DopplerScatt Results: What we have learned and implications for a Winds and Currents Mission

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DopplerScatt Overview

DopplerScatt Programmtic Overview

Scanning Doppler radar developed under NASA's IIP program

Becoming operational under NASA AITT program by 2019

Data Products:

1. Vector ocean surface currents
2. Vector ocean surface winds
3. Radar brightness maps (sensitive to surfactants such as oil films)

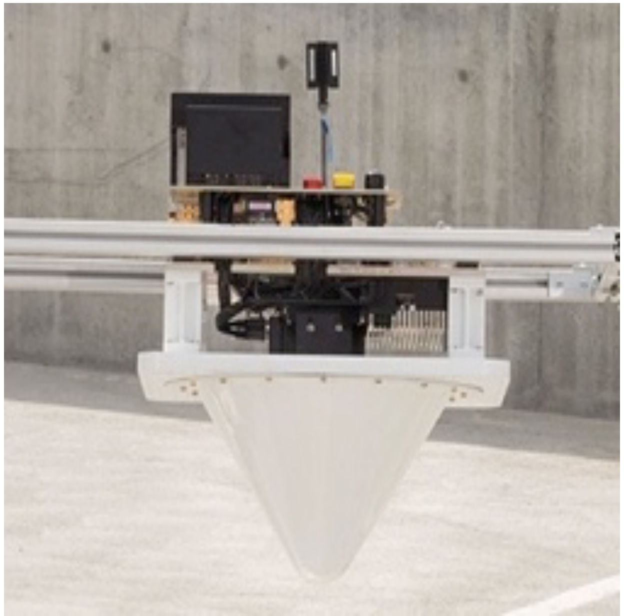
Data products are still being refined under AITT. Will be posted in NASA PODAAC when finished.

Mapping capabilities:

- 25 km swath
- maps 200km x 100km area in about 4 hrs
- 200m data product posting
- Mapping within ~600 m of coast
- ~5-10 cm/s radial velocity precision.
- ~ 1 m/s wind speed, <20° wind direction.

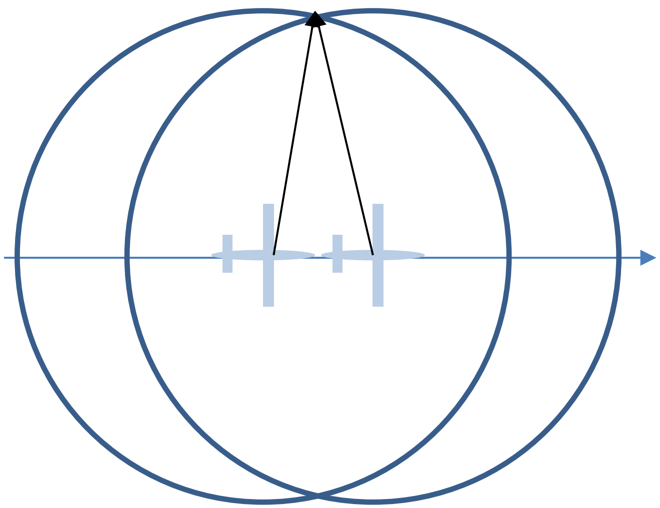
Campaigns flown/planned:

- Oregon coast (2016)
- SPLASH (Submesoscale Processes and Lagrangian Analysis on the Shelf) in Mississippi River Plume
- (CARTHE) & Taylor Oil Platform Plume (NOAA), April 18-28, 2017.
- KISS-CANON in Monterey Bay May 1-4, 2017.
- California current (September, 2018)

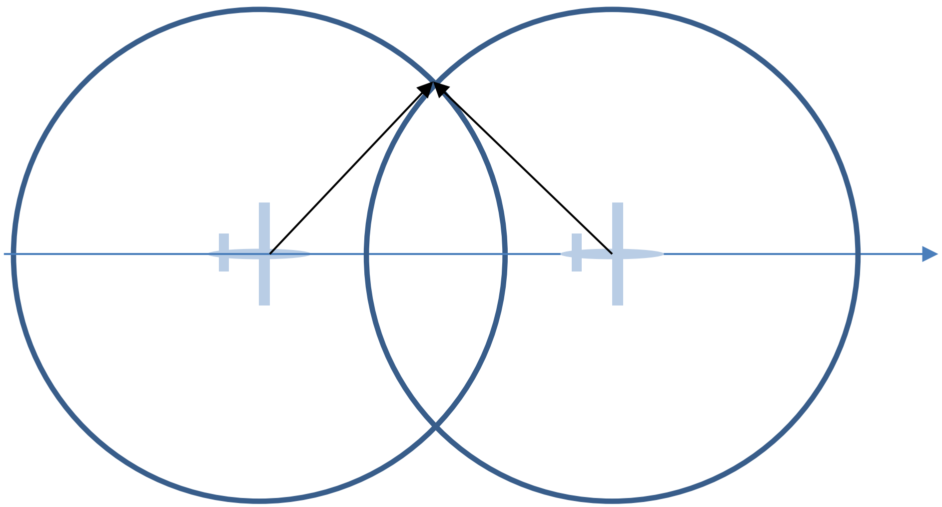


DopplerScatt instrument. It has been deployed on a DOE King Air and will transition to an operational instrument in the NASA King Air B200.

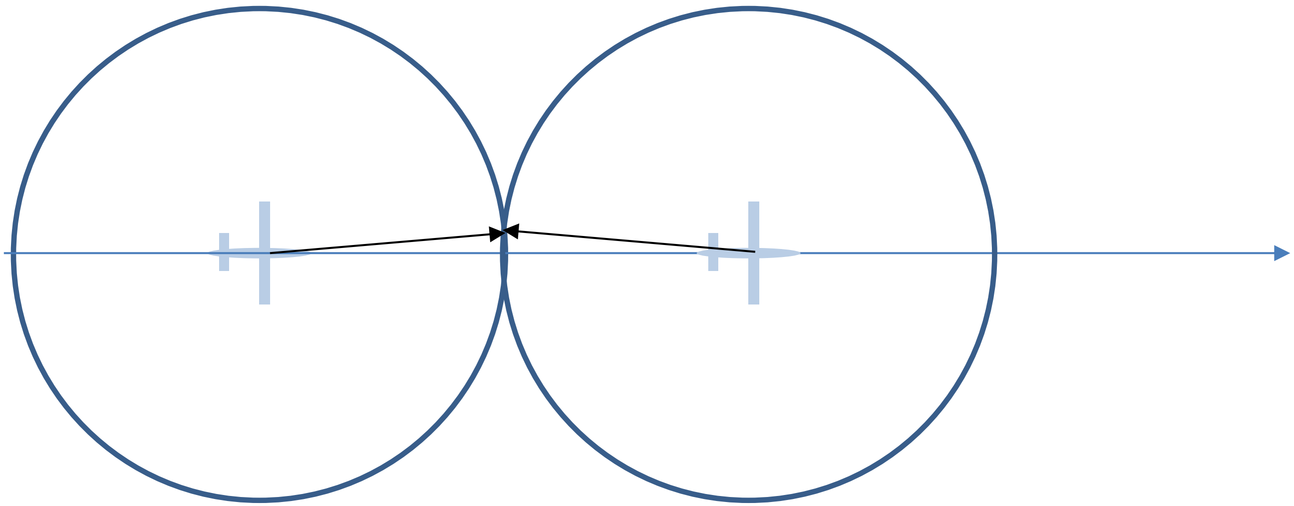
DopplerScatt Vector Estimation



Bad azimuth diversity

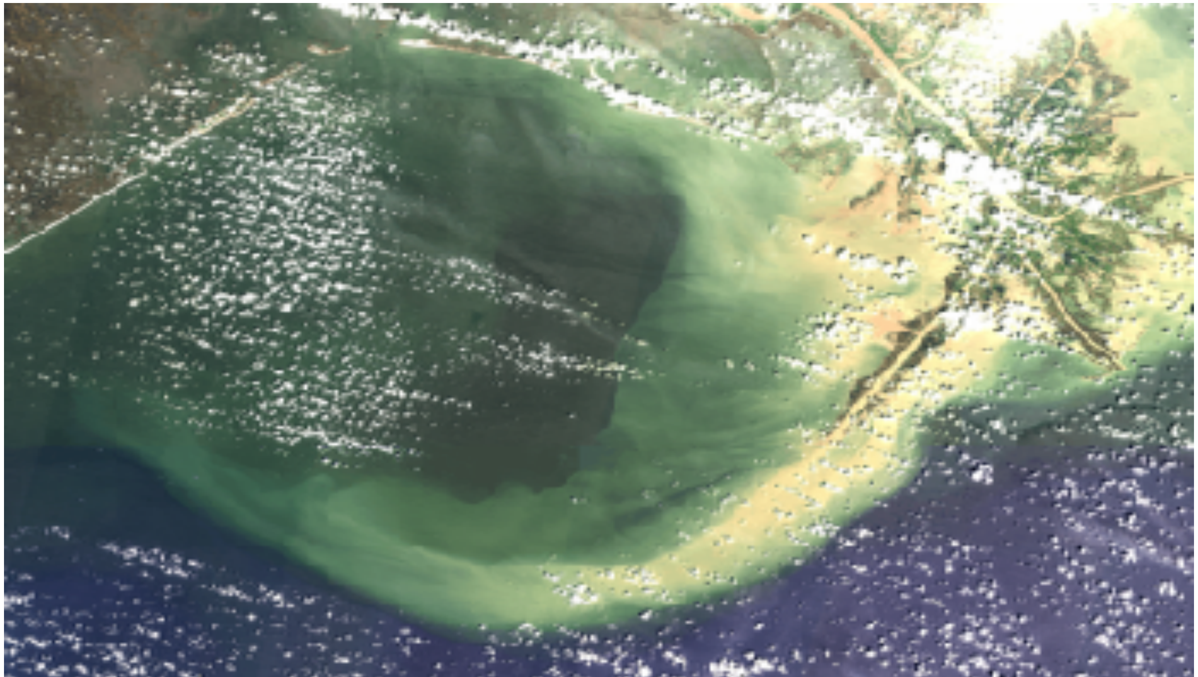


Good azimuth diversity

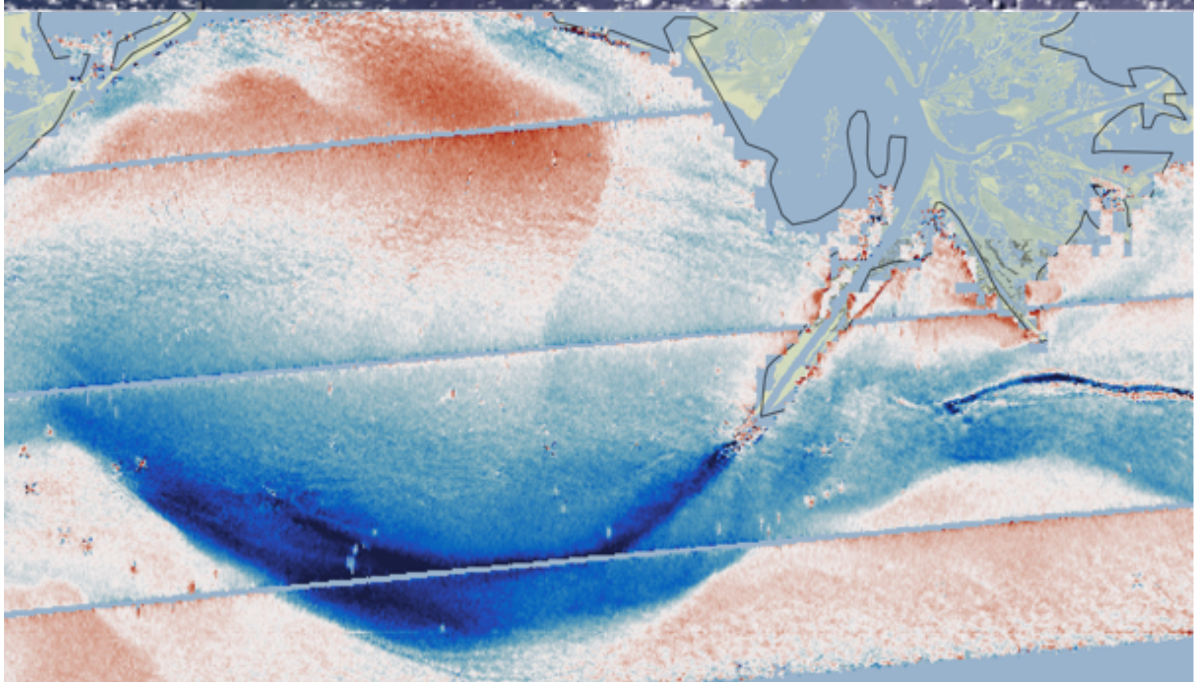


Bad azimuth diversity

SCIENCE



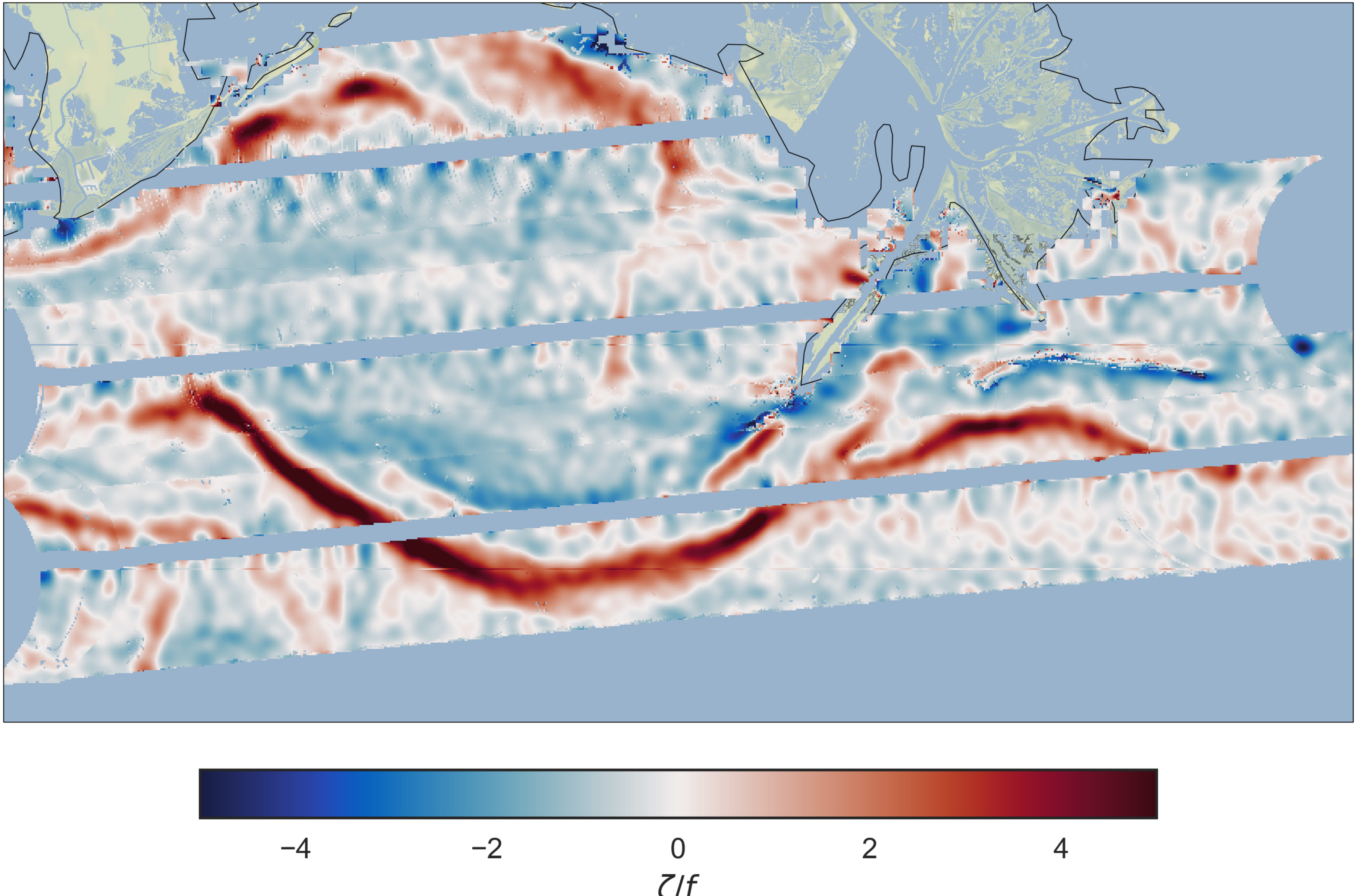
Sentinel 3 2017-04-18
Courtesy of Copernicus Sentinel, processed by ESA



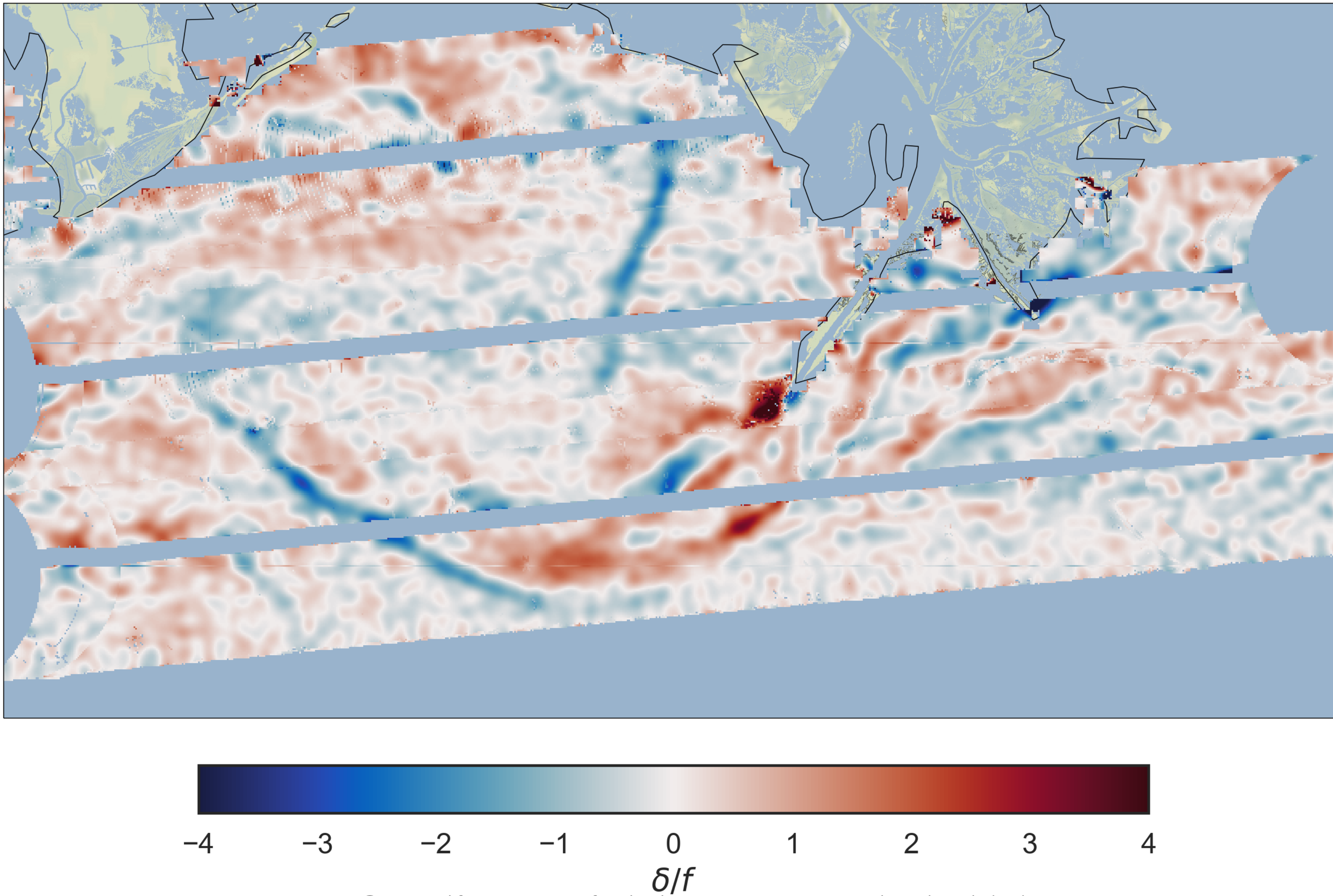
DopplerScatt surface current U component.

Circulation pattern matches Sentinel 3 color pattern very closely.

Relative Vorticity



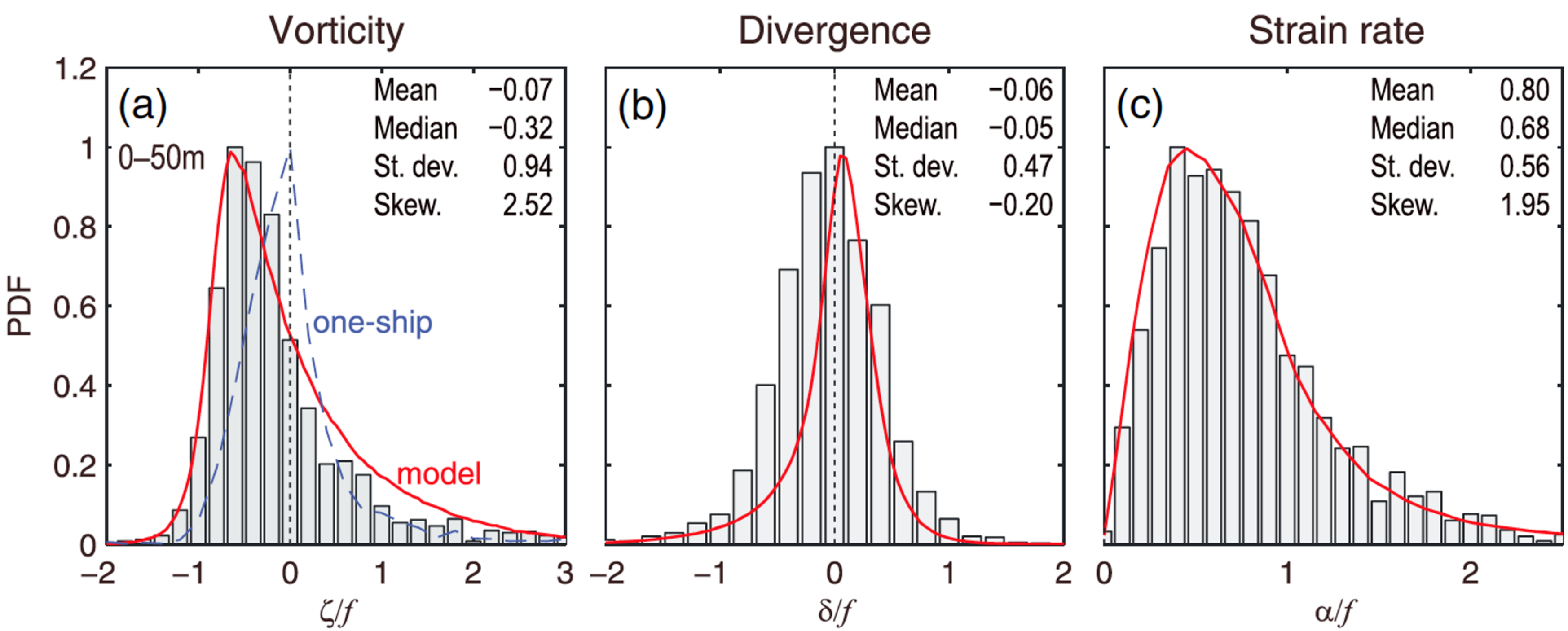
Divergence



Derivative PDFs from Shcherbina et al., GRL, 2013

Data collected by two ships traveling 1 km apart in parallel for 500 km and using ADCPs

SHCHERBINA ET AL.: SUBMESOSCALE TURBULENCE STATISTICS



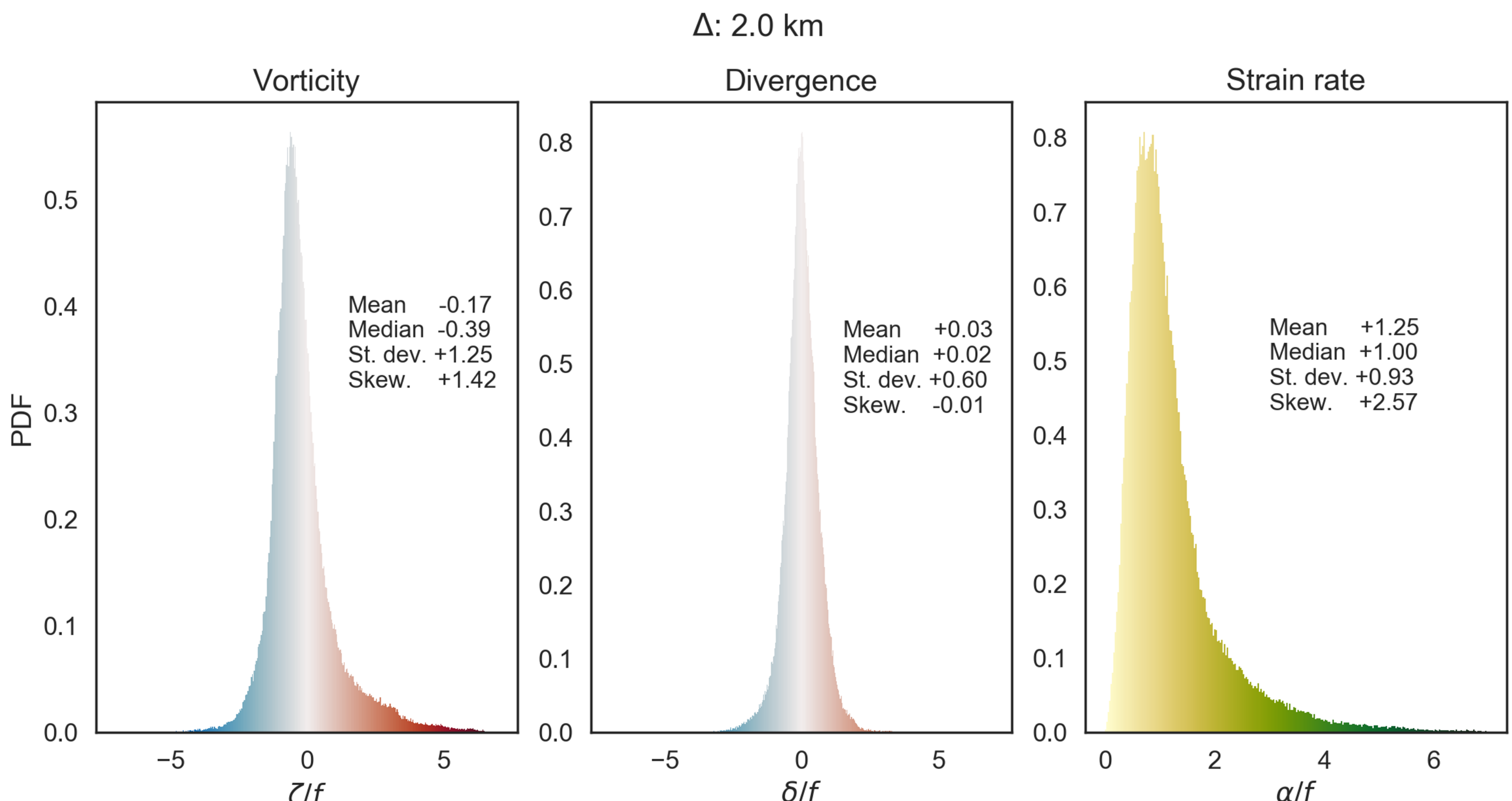
Skewness > 0 expected as ζ>0 structures have greater stability

Divergence range smaller than vorticity. Slightly skewed towards convergence.

Strain rate approximately chi-squared distributed.

DopplerScatt Derivative PDFs

Derivatives show similar statistics to Shcherbina et al. 2013



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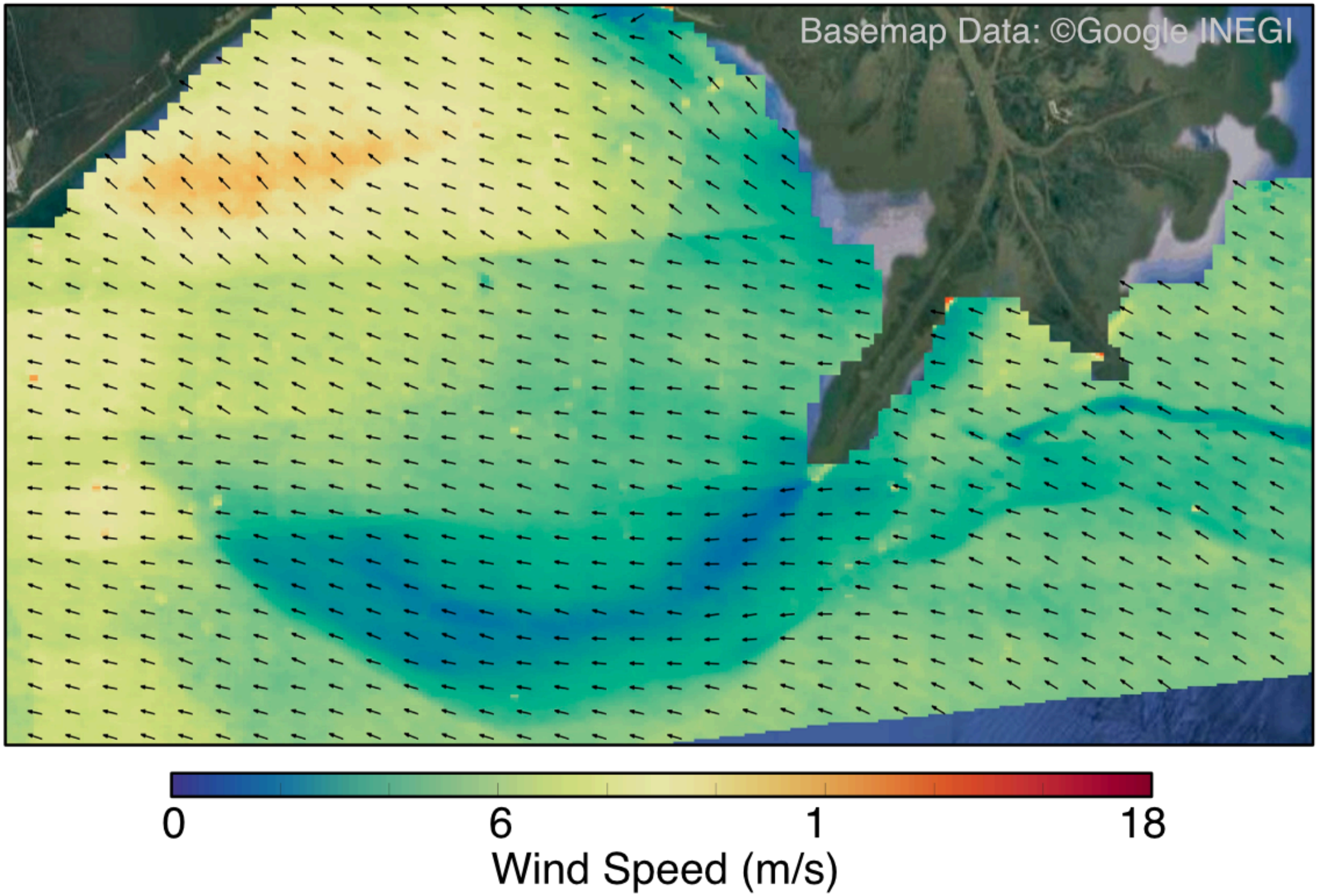
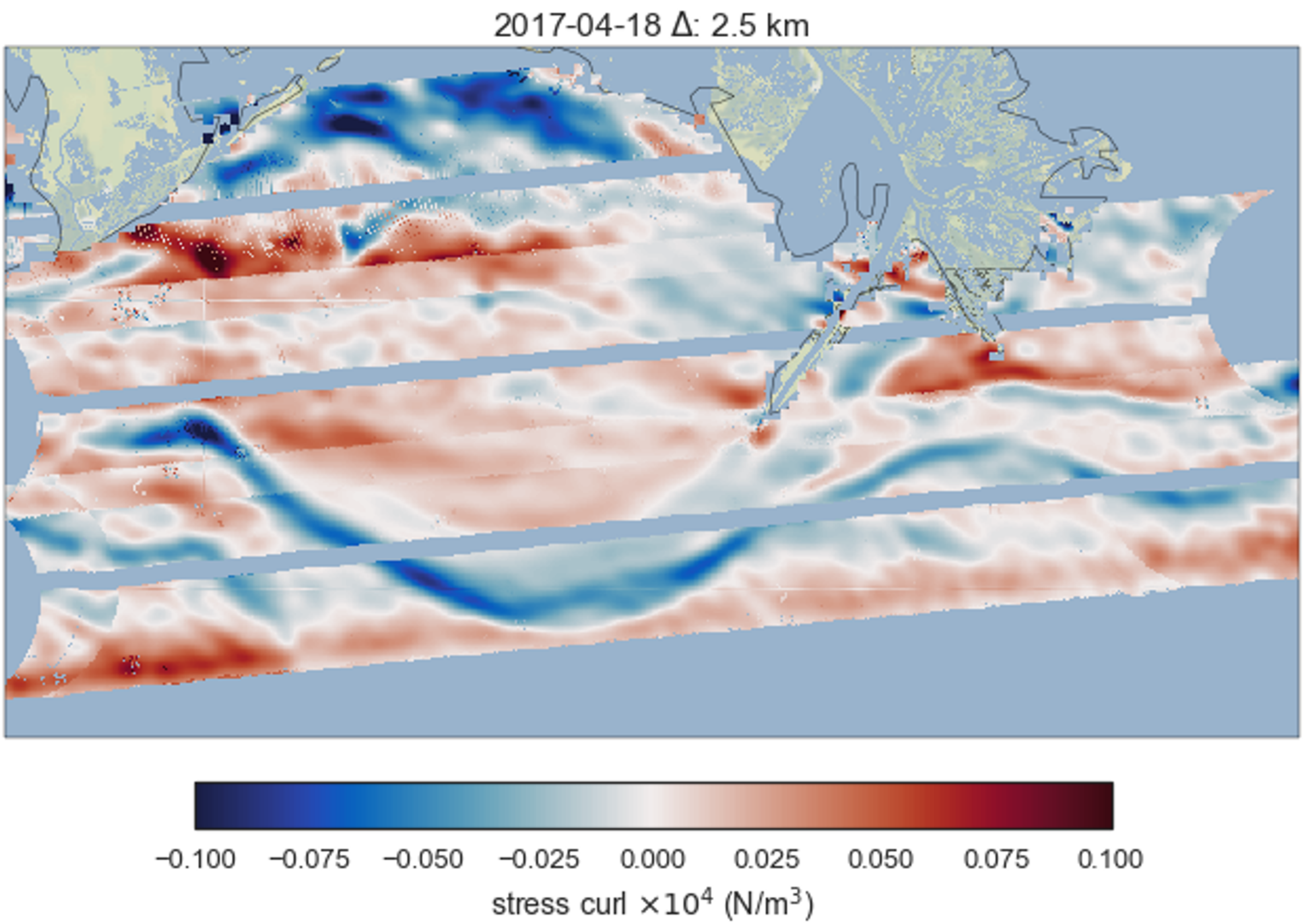
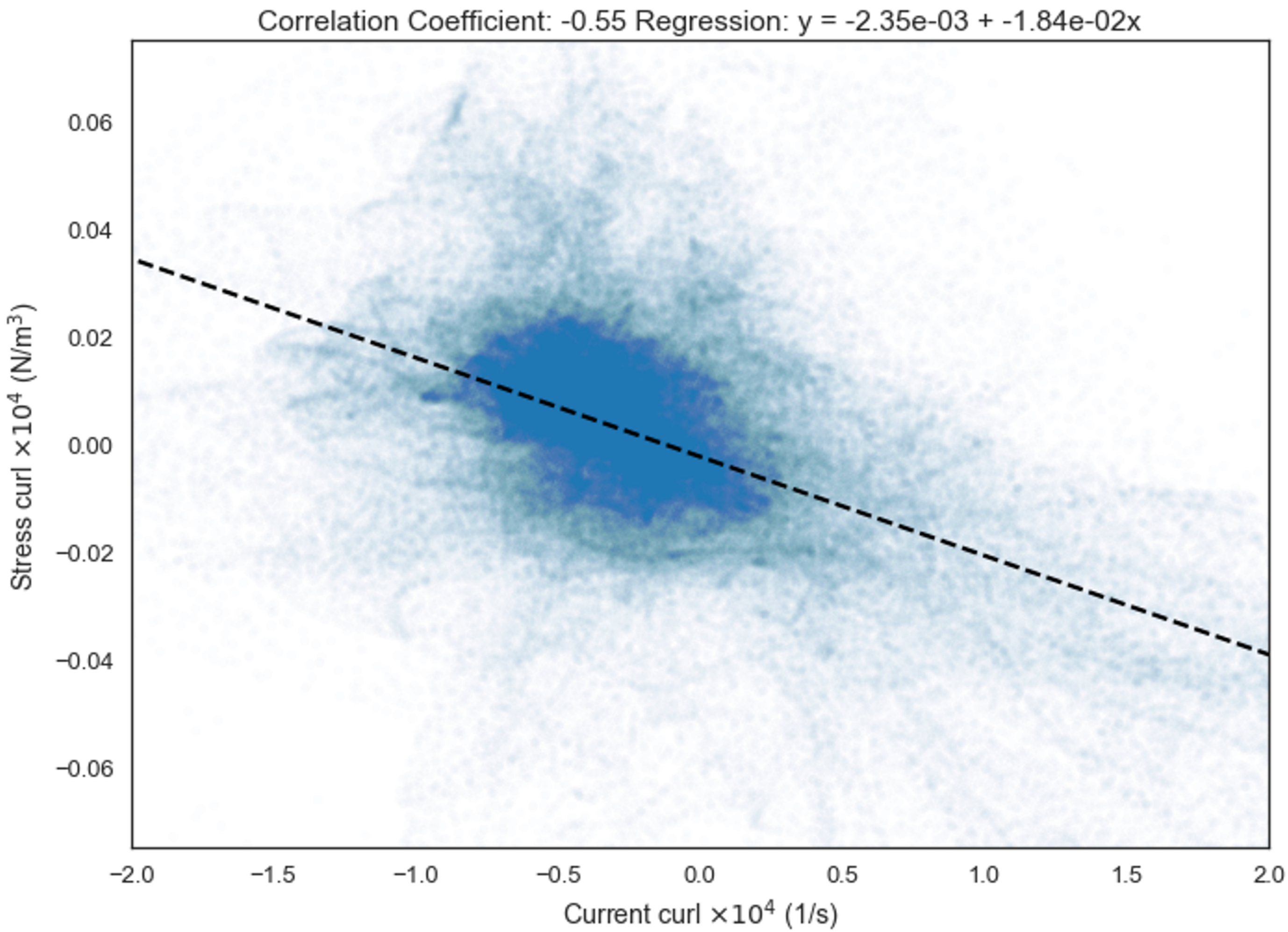
Winds



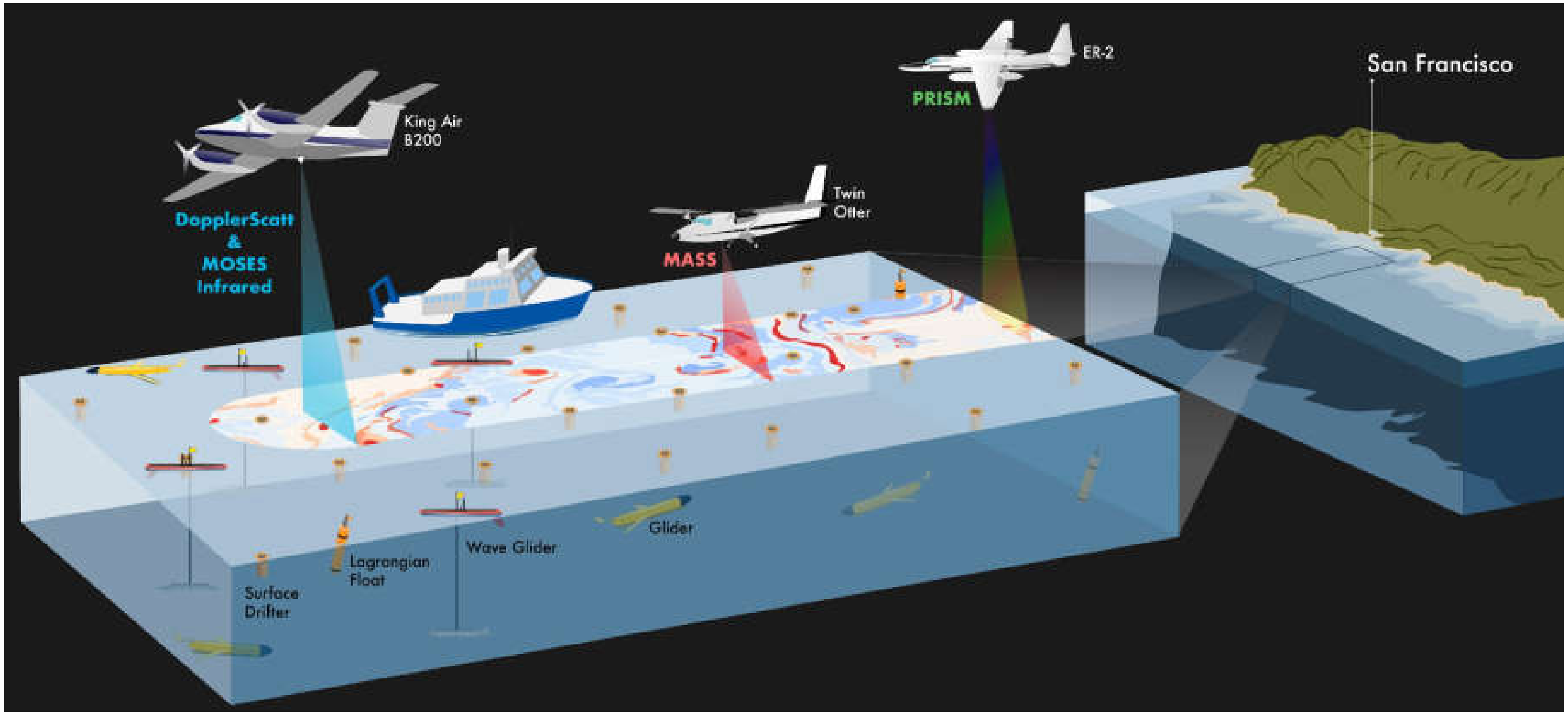
Wind Stress Curl



Wind Stress Curl vs Relative Vorticity



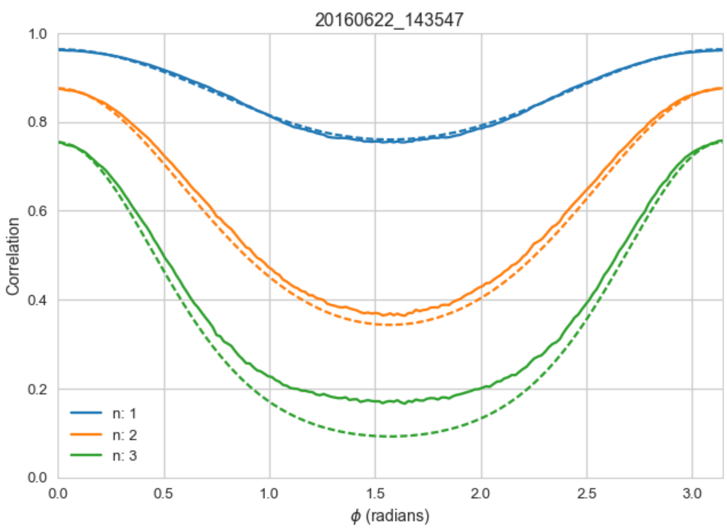
Coming up

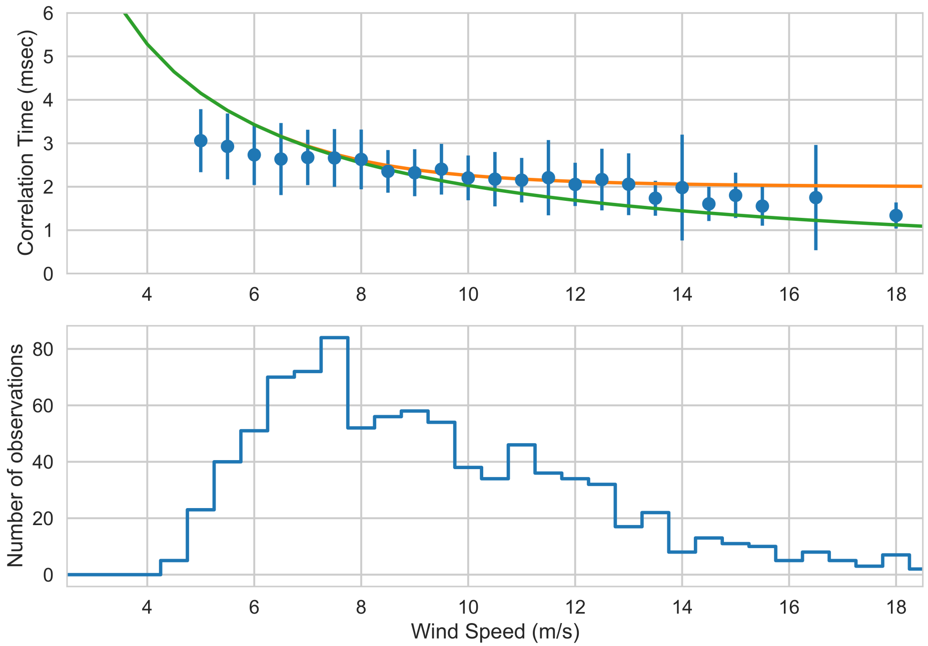


- SMODE: Sub-Mesoscale Ocean Dynamics Experiment
- NASA Earth Ventures Suborbital-3: 2019-2023
- PI Tom Farrar (WHOI)

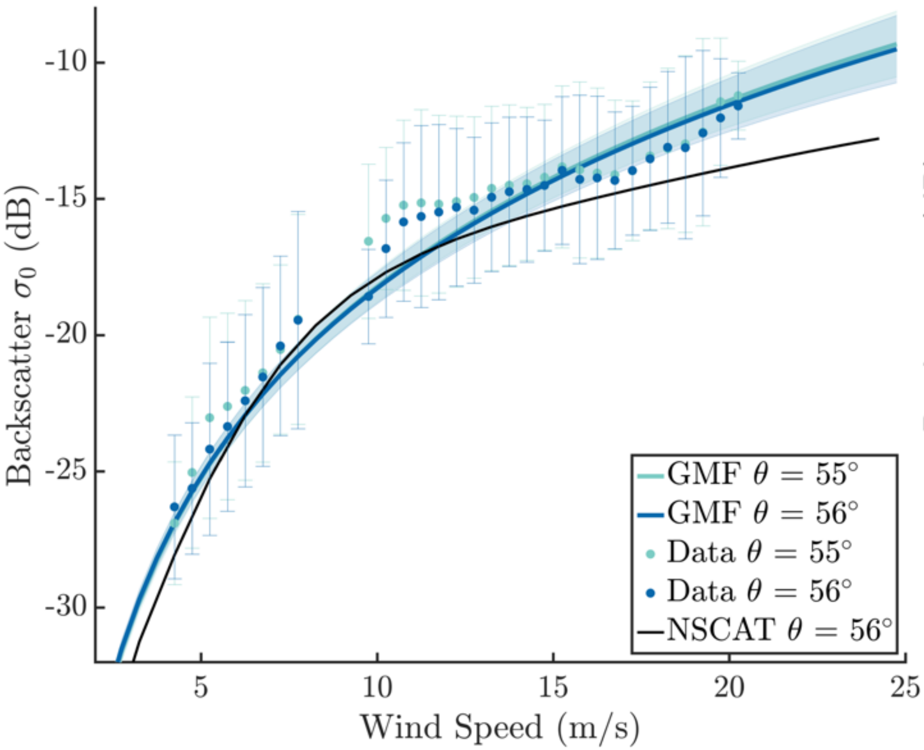
PHENOMENOLOGY

Correlation

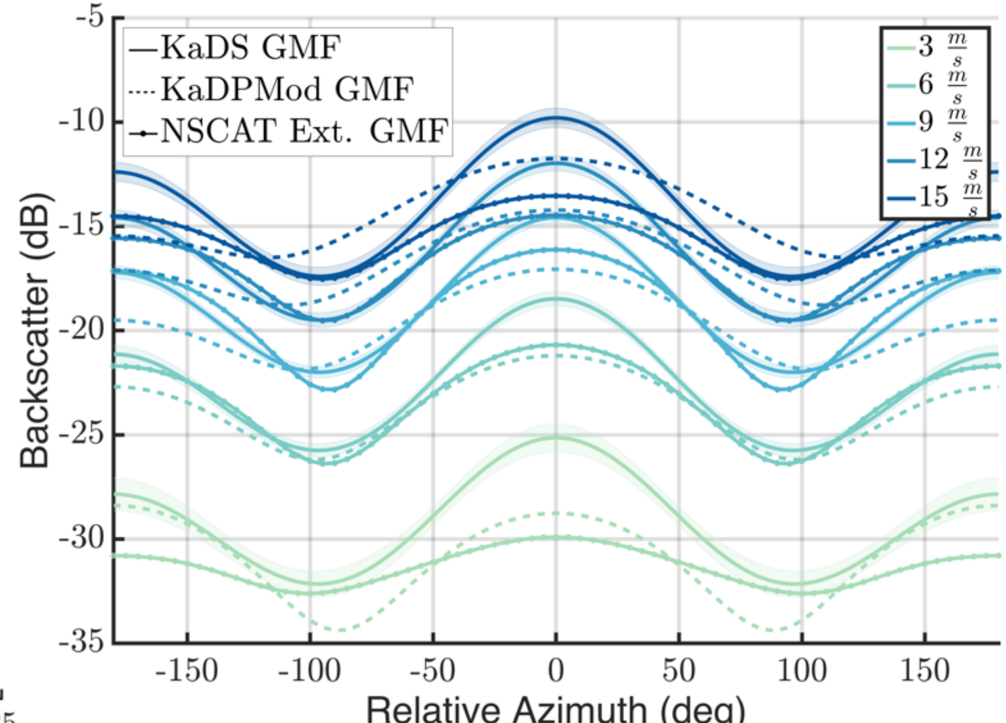




Scatterometer Wind GMF



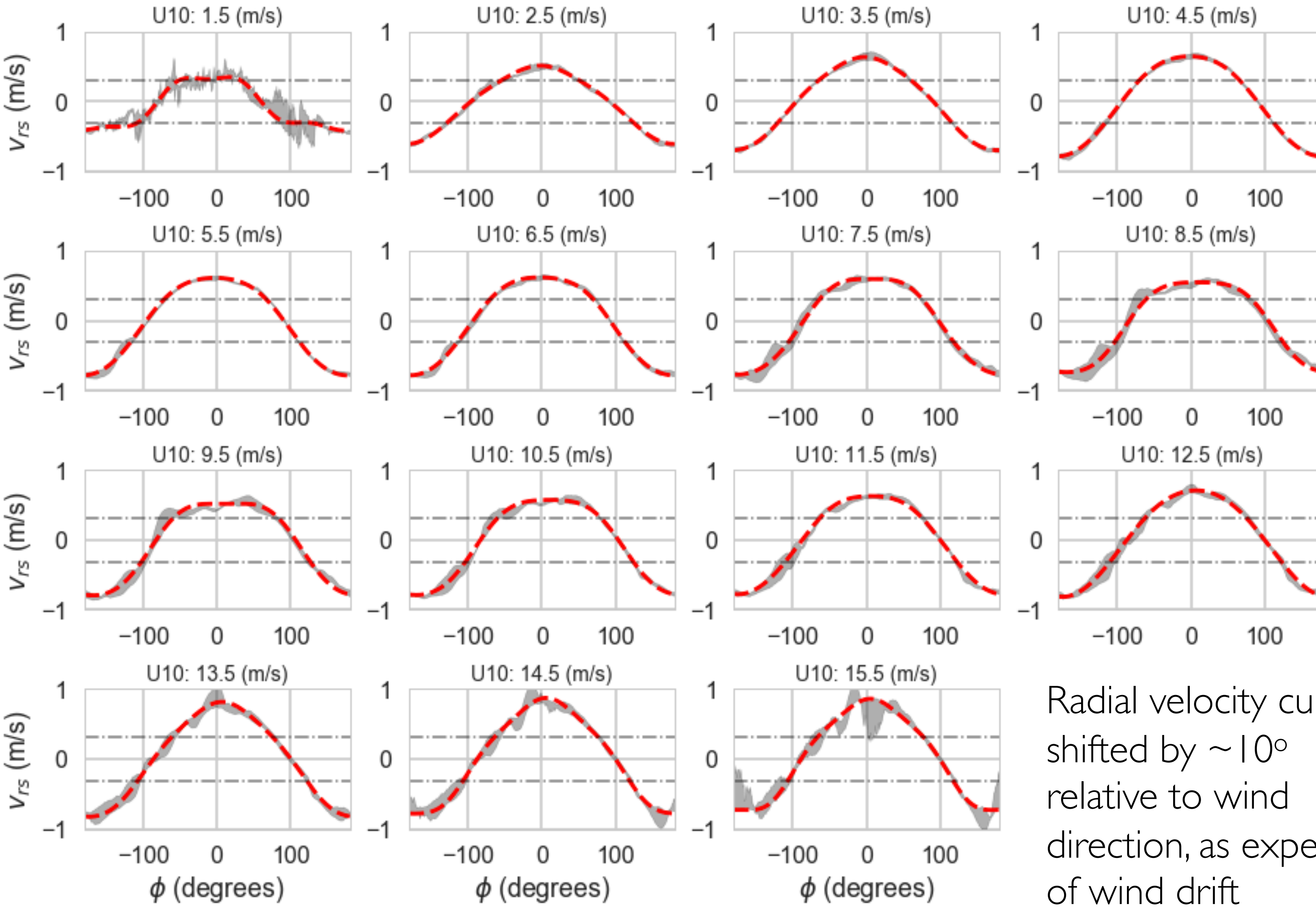
The mean radar backscatter increases with wind speed.



The backscatter intensity is modulated as a function of azimuth angle relative to wind direction.

- By combining measurements from multiple azimuth angles, wind speed and direction can be estimated. Ku & Ka backscatter have similar characteristics, so both are suitable for wind estimation.
- Experiments have shown that backscatter is proportional to wind stress (although normally parametrized as neutral wind).

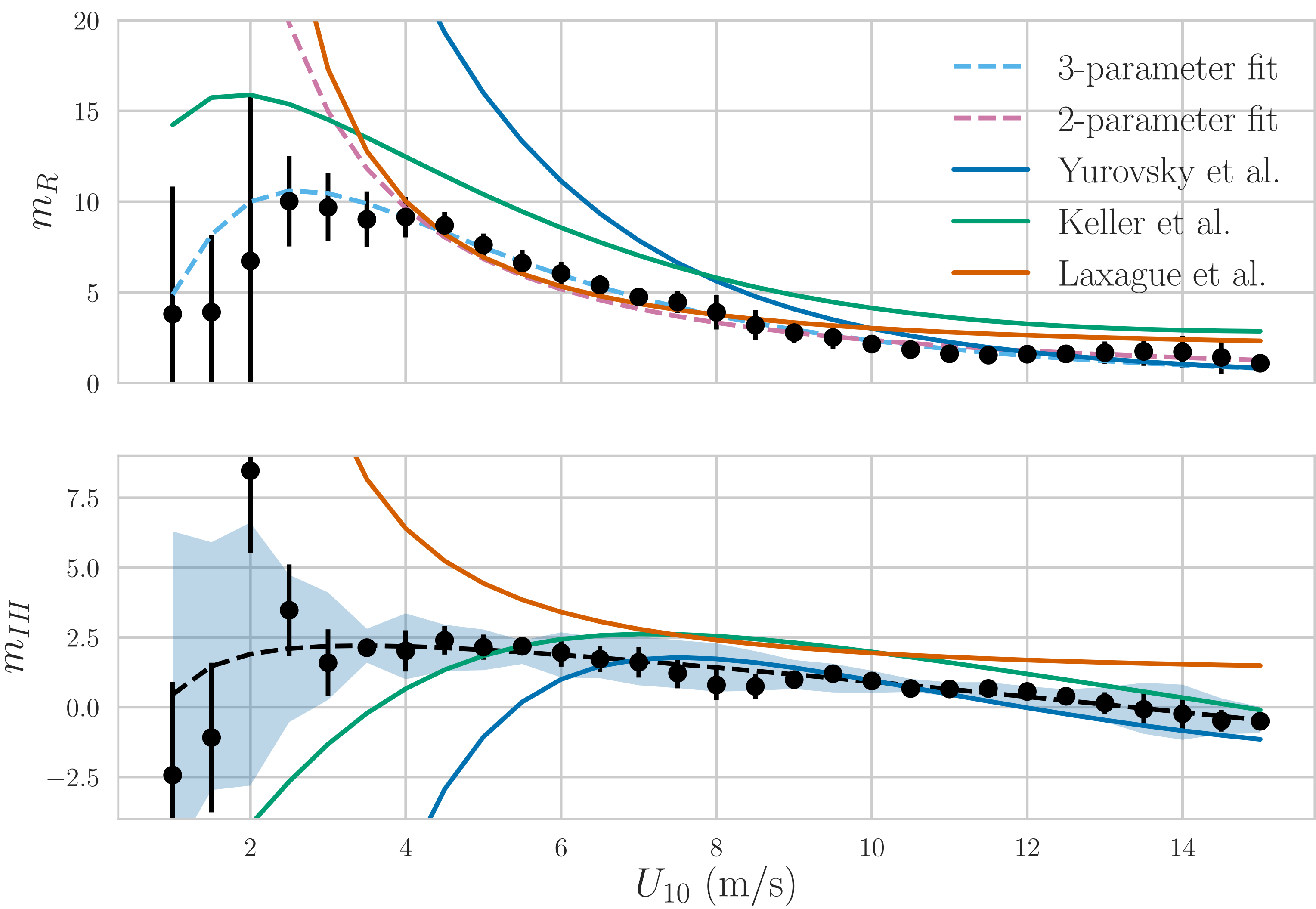
Radial Velocities Binned by Wind Direction



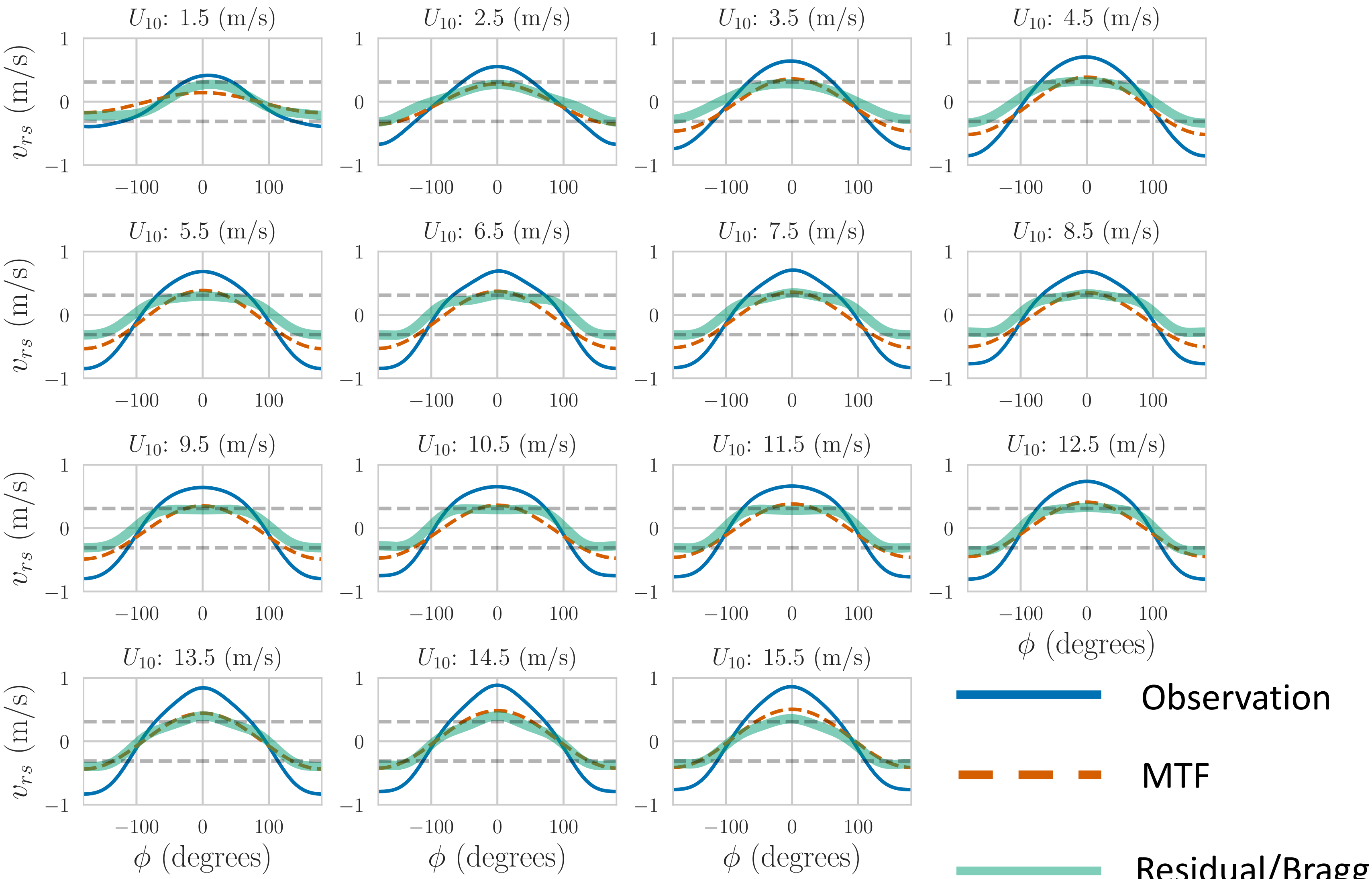
Radial velocity currents shifted by ~10° relative to wind direction, as expected of wind drift

Dot-dash lines indicate Bragg phase velocities

Hydrodynamic Modulation

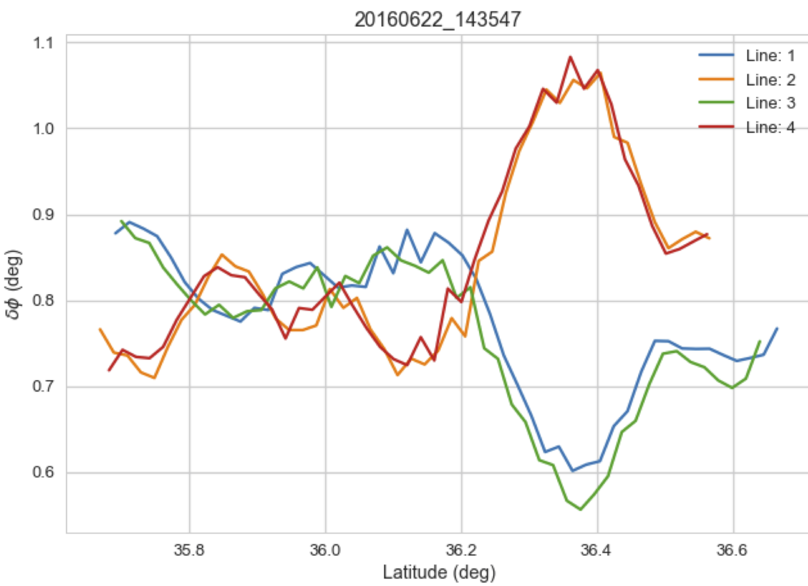


Radial Velocity Decomposition

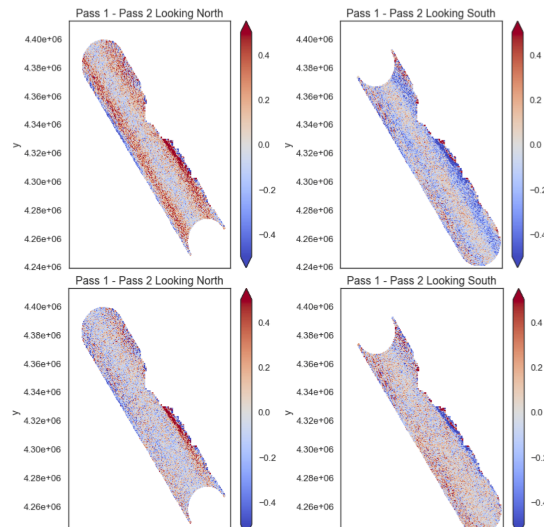


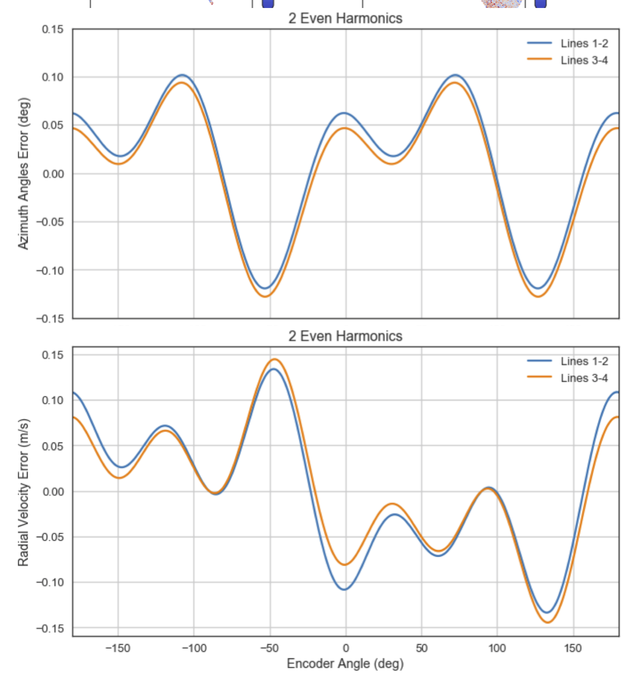
CALIBRATION

Calibration Effects



Currents influence calibration results

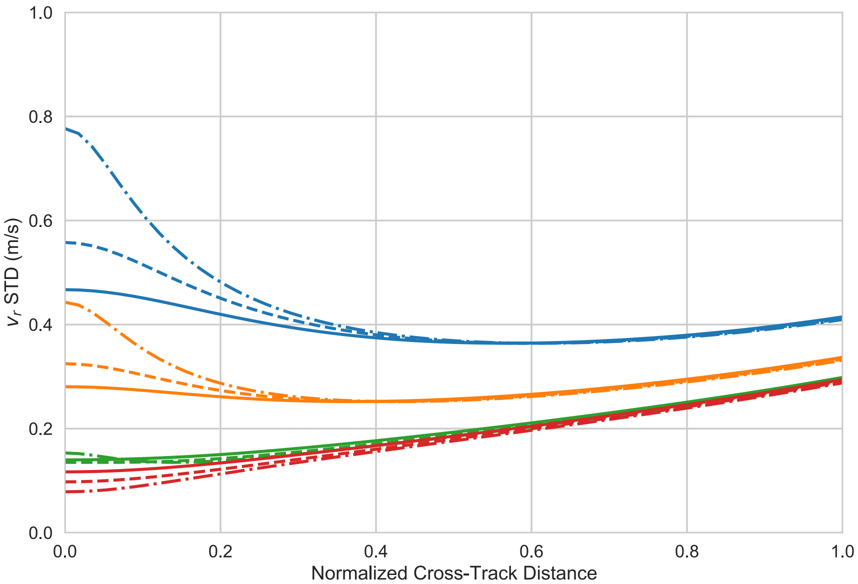


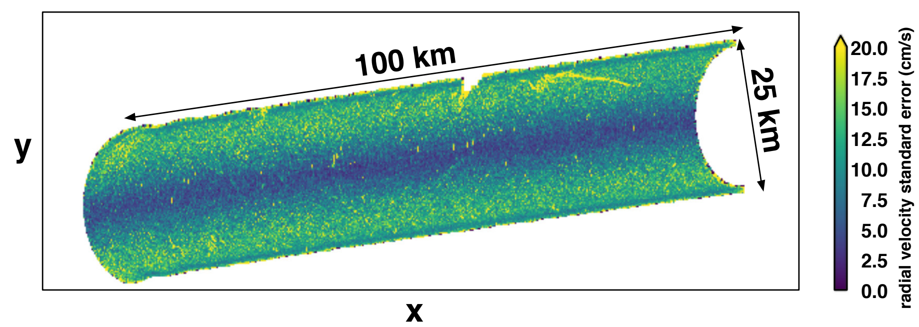


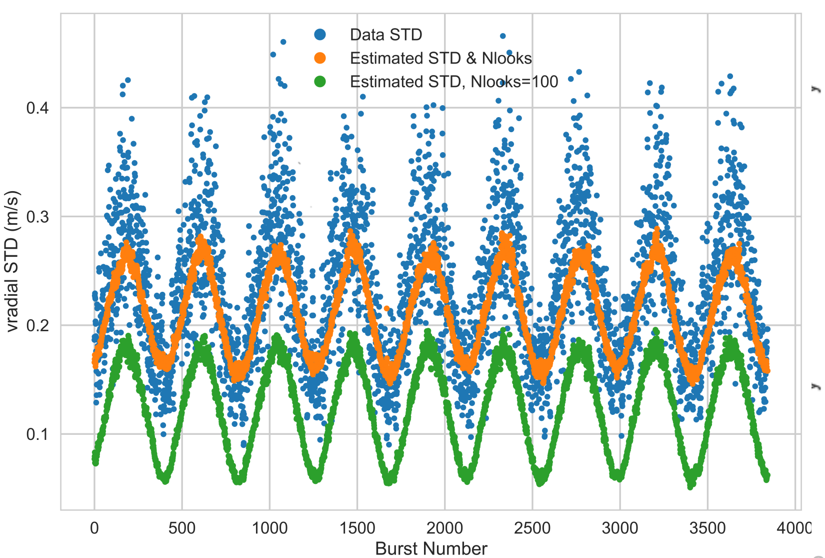
A simple harmonic calibration is mot sufficient

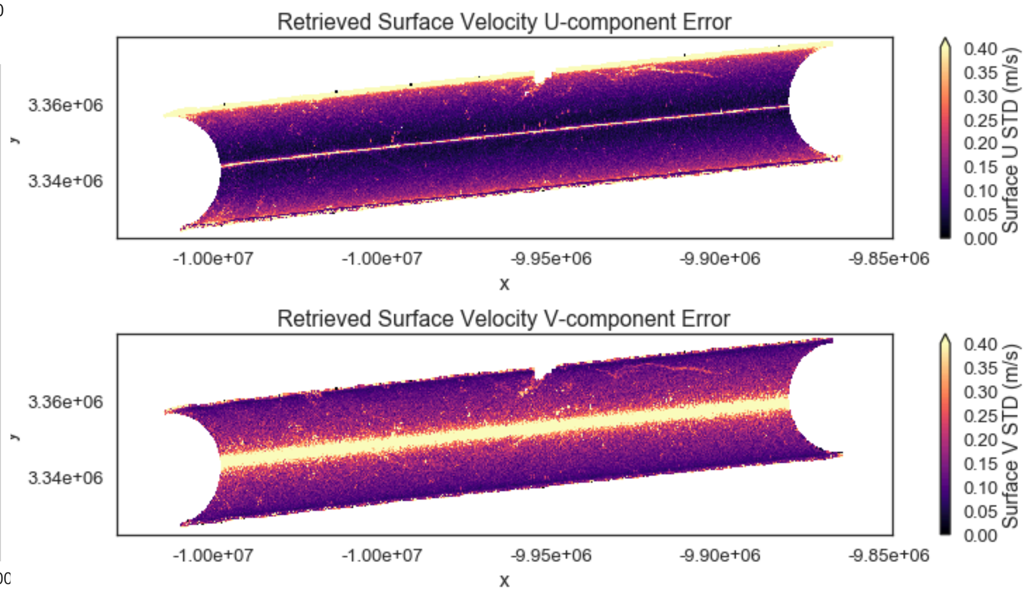
ERROR MODEL VALIDATION

Surface Velocity Random Errors



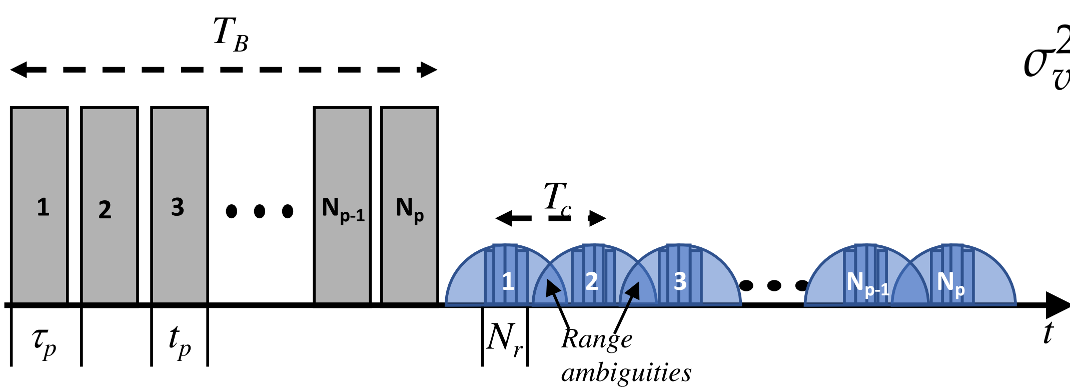






SPACEBORNE SYSTEM DESIGN

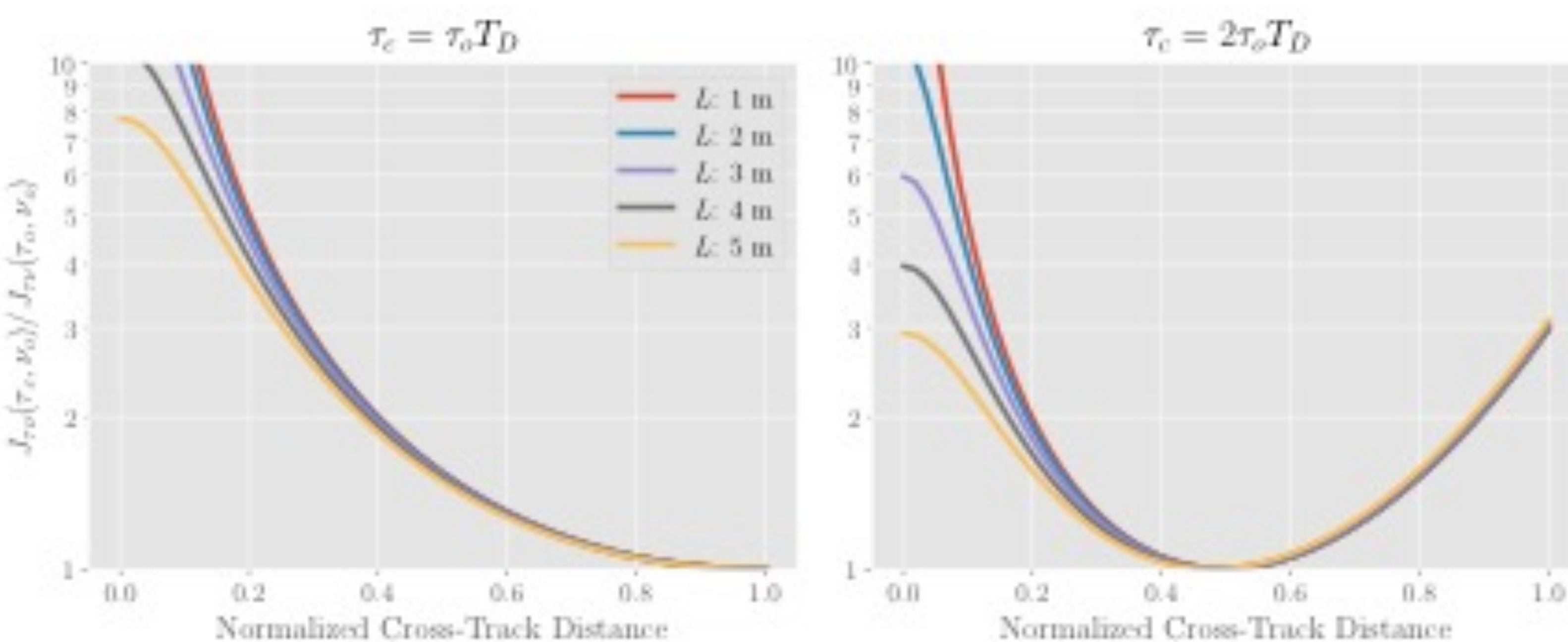
Lesson 1: Optimize Pulse Separation by Keeping Pulse Correlation Constant



$$\sigma_{vr}^2 = \left(\frac{1}{2k\tau_p}\right)^2 \frac{1}{2N_rN_b}\frac{1-\gamma^2}{\gamma^2}$$

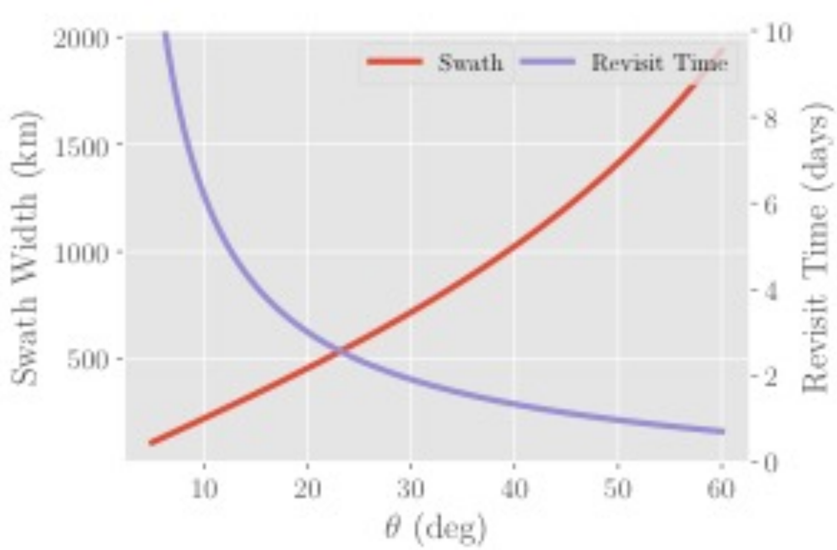
Pulse separation as long as possible

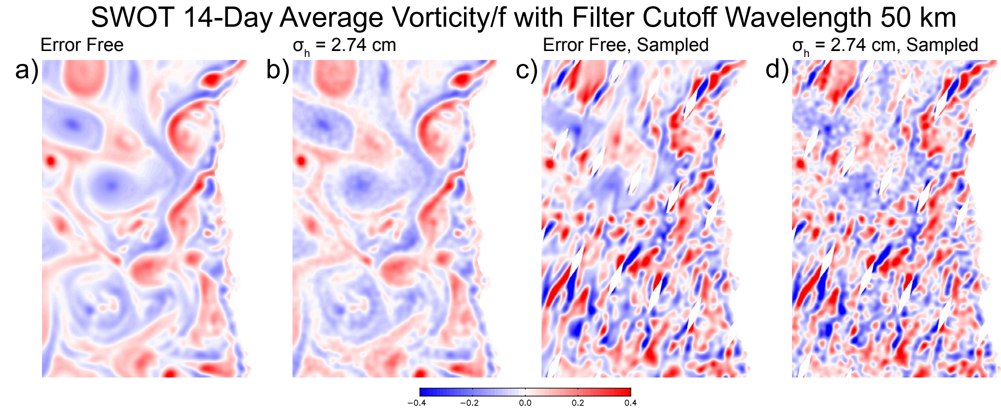
Pulses as correlated as possible

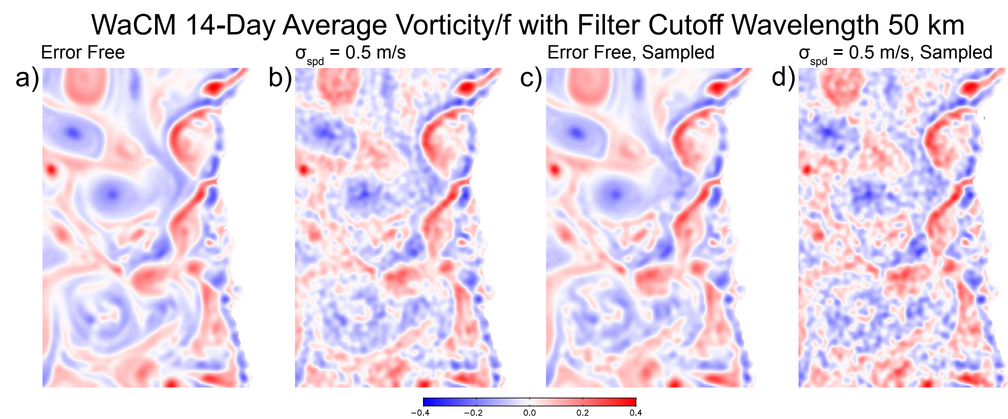


Lesson 2: Minimize Temporal Aliasing by Achieving the Widest Swath Possible

Wide swath & temporal sampling are key



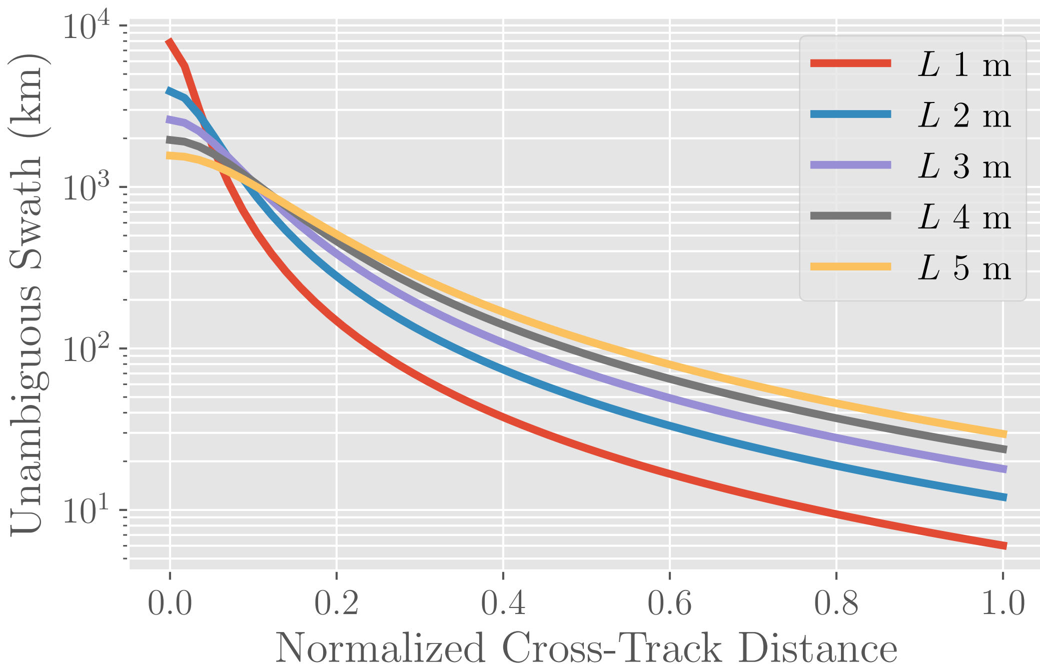


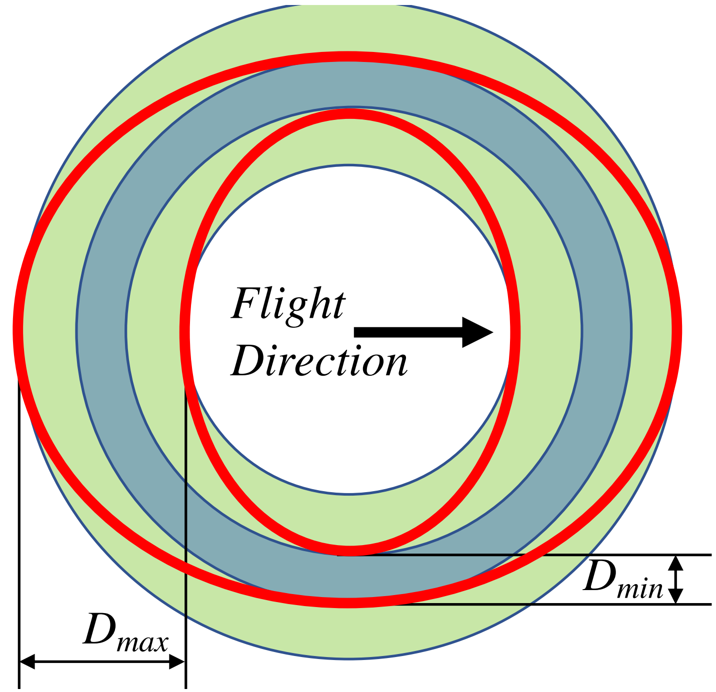


From Chelton et al, 2018
Prog. Ocean. In press

WaCM samples O(2x/day) so that inertial and tidal signal aliasing is minimized in temporal averages.

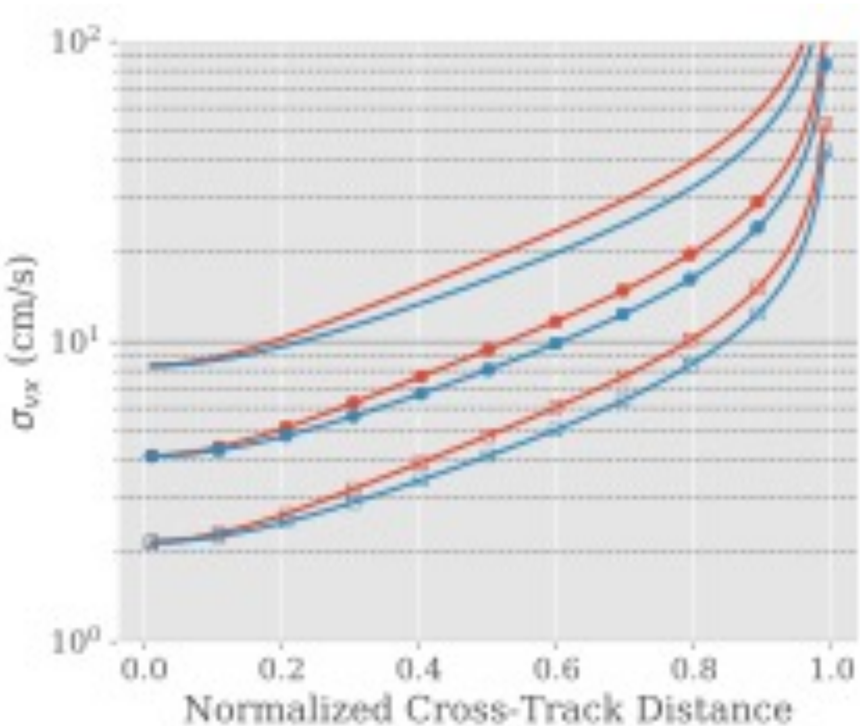
Lesson 3: Minimize Mapping Error by Coverage Minimizing Gaps

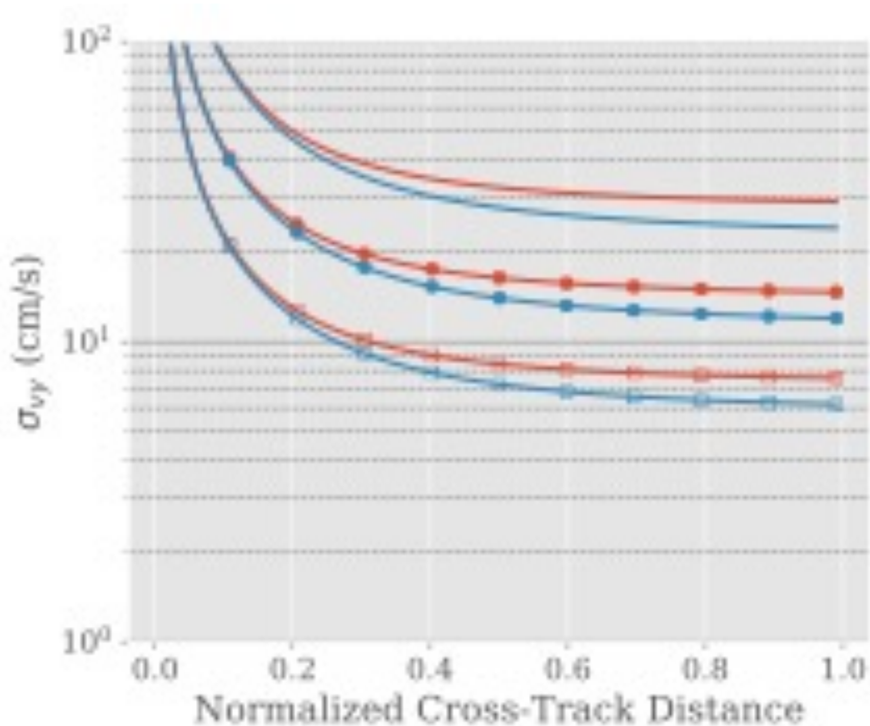




By varying the PRF, its is easier to achieve swath continuity

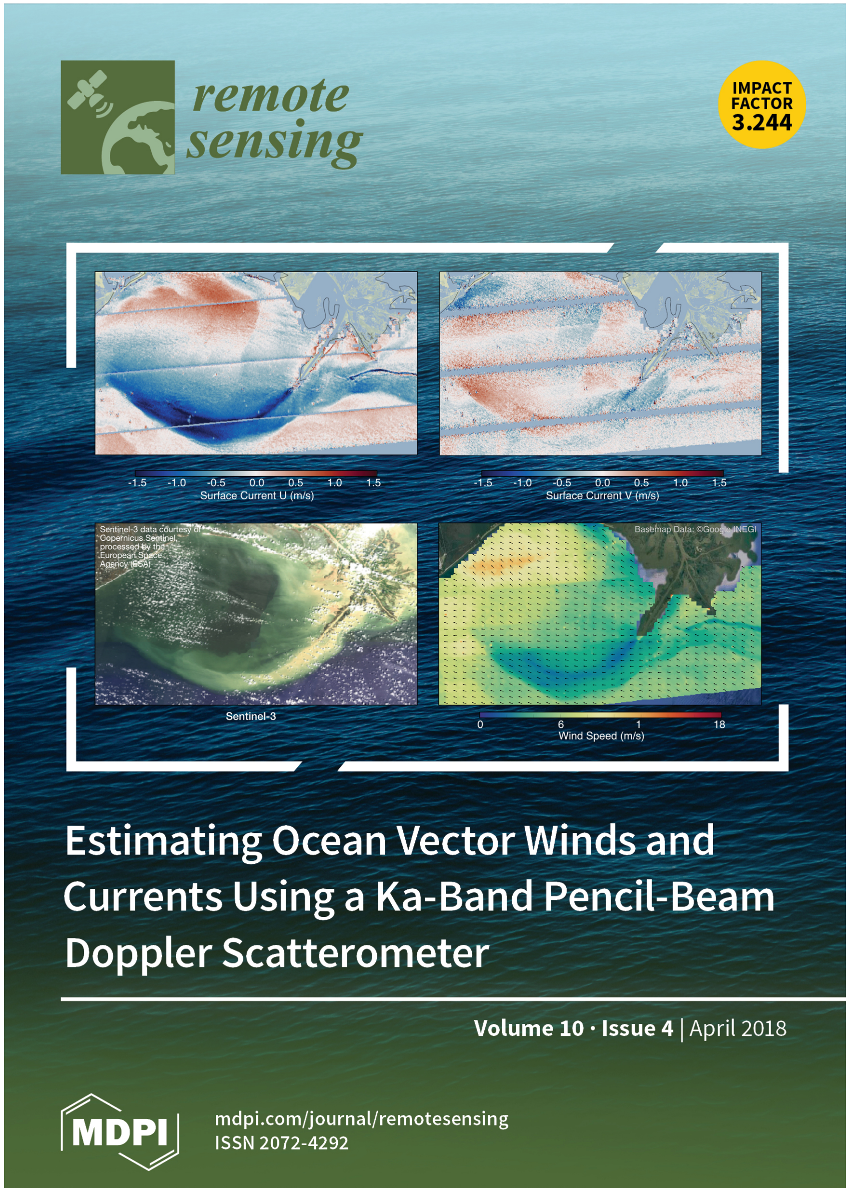
WaCM Performance at 5km Sampling





Antenna length: 4m (blue), 5m (red)
Peak Transmit Power:
100 W: solid lines
400 W: circles
1.5 kW: empty squares

References



Article

On the Optimal Design of Doppler Scatterometers

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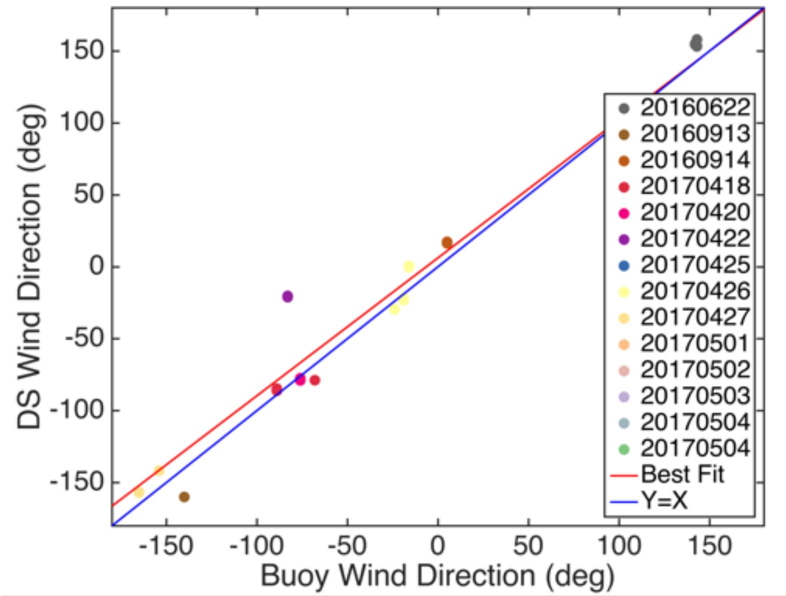
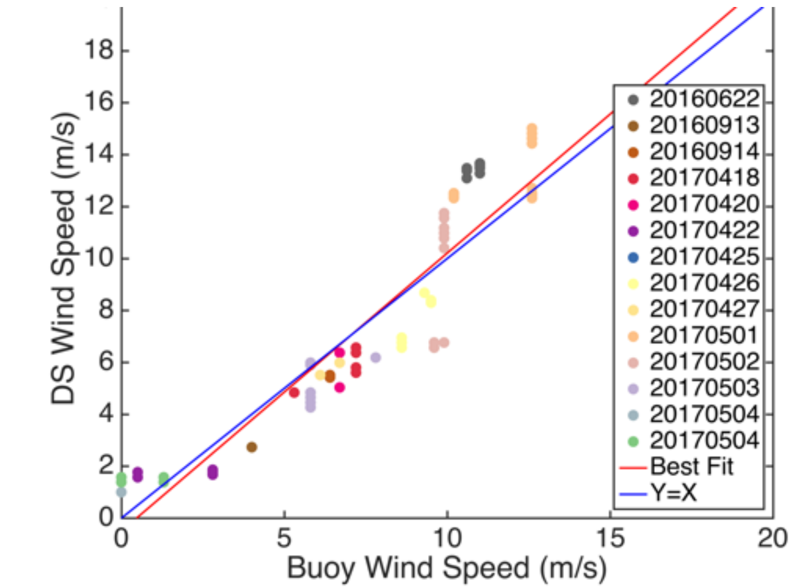
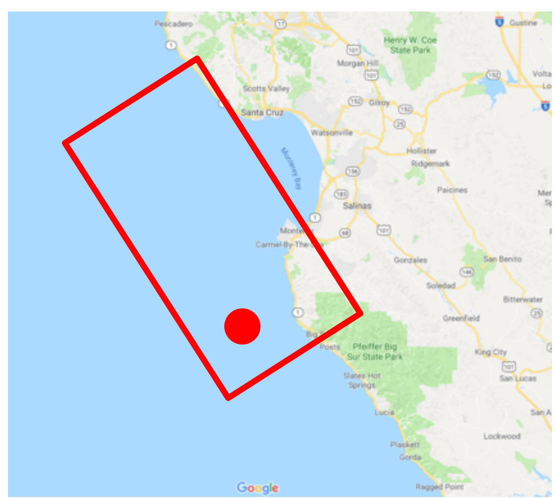
https://www.preprints.org/manuscript/201810.0106/v1

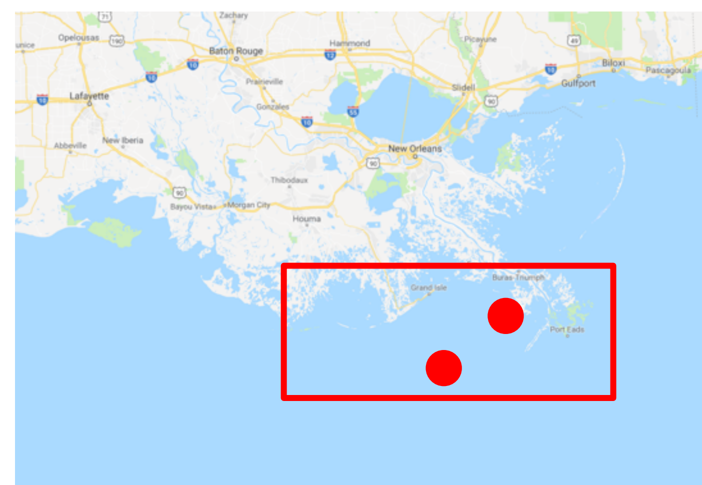
BACKUPS

DopplerScatt Wind Validation





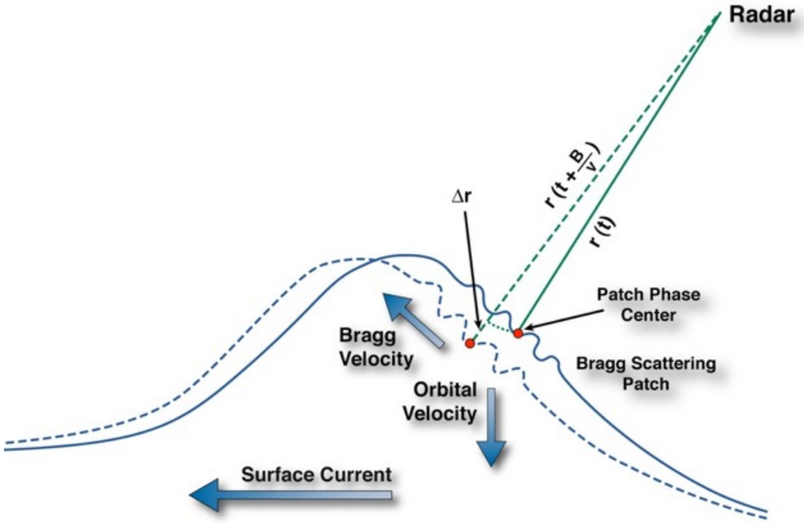




What velocity are we measuring?

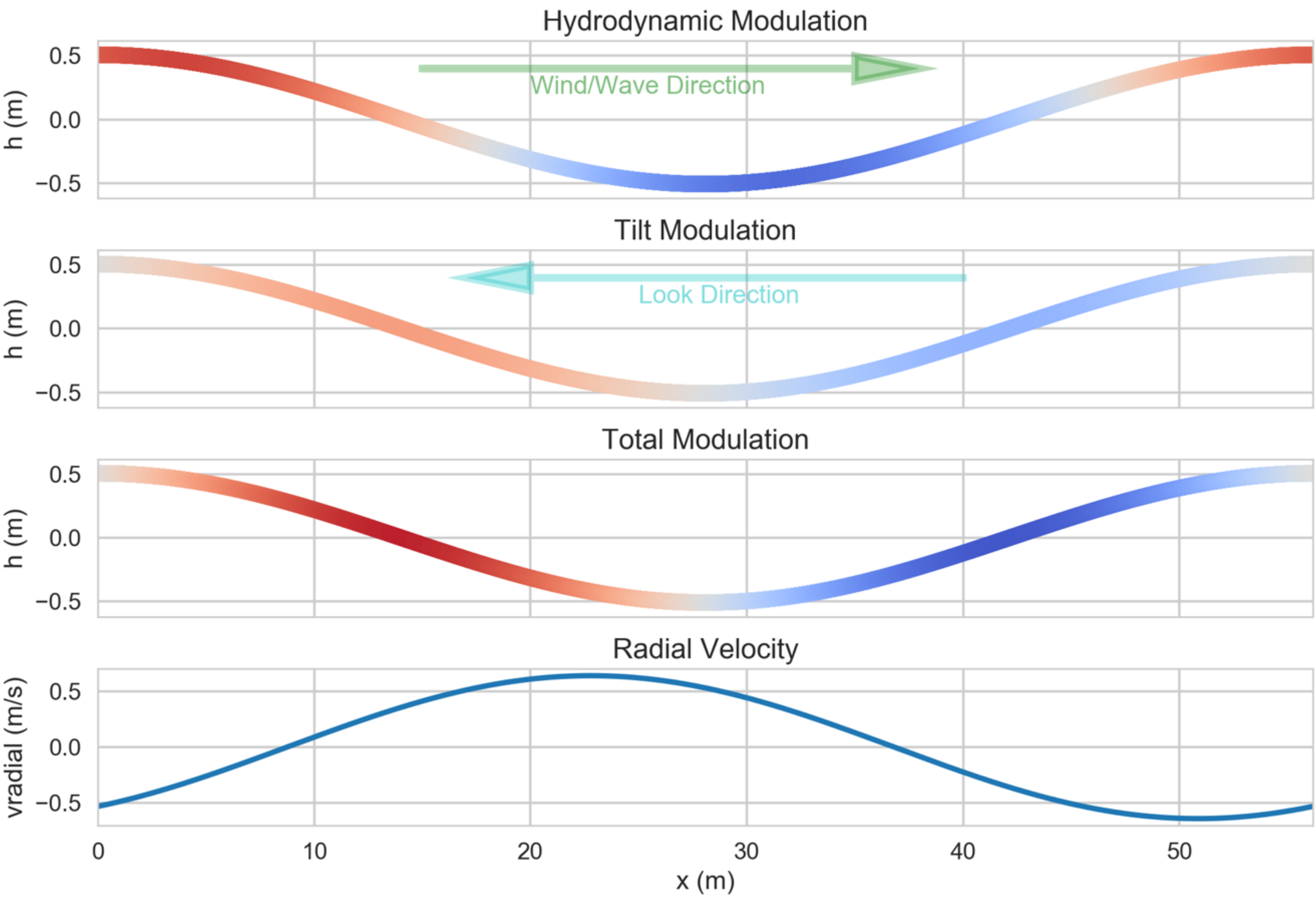
$$\Phi = \frac{2\pi}{\lambda}\Delta r$$

$$v_{scatterer} = \frac{\Delta r}{B} v_{platform}$$



- Radar sensitive to phase speed ~0.5 cm capillary waves
- Free wave phase speed: ~31 cm/s. Capillary waves can also be generated as bound waves due to straining: will travel at straining wave phase speed (low wind speeds).
- Phase speed modulated by surface currents. Winds will add Stokes drift & surface drift.
- Gravity wave orbital velocity is added to capillary wave velocity. When averaging over surface waves, velocity is weighted (by radar brightness) spatial average.
- Brightness not homogeneous over long wave:
  - Hydrodynamic modulation due to 1) capillary amplitude modulation by spatially varying orbital velocity,; 2) wave breaking; 3) bound waves

Radar Brightness Modulation



Observation Model

$$\eta = \sum_n a_n \cos \Theta_n \eta_x$$

Gravity wave height

In phase with *u*   In phase with *w*

$$\left.\frac{\delta\sigma_0}{\sigma_0}\right|_{\mathrm{Hydro}} = m_r \sum_n a_n k_{xn} \cos \Theta_n - m_i \sum_n a_n k_{xn} \sin \Theta_n$$

Hydrodynamic modulation

In phase with *w*

$$\left.\frac{\delta\sigma_0}{\sigma_0}\right|_{\mathrm{Tilt}} = -m_T \cos \phi_r \sum_n a_n k_{xn} \sin \Theta_n = \frac{\partial \log \sigma_0}{\partial \theta} \cos \phi_r \eta_x$$

Tilt modulation

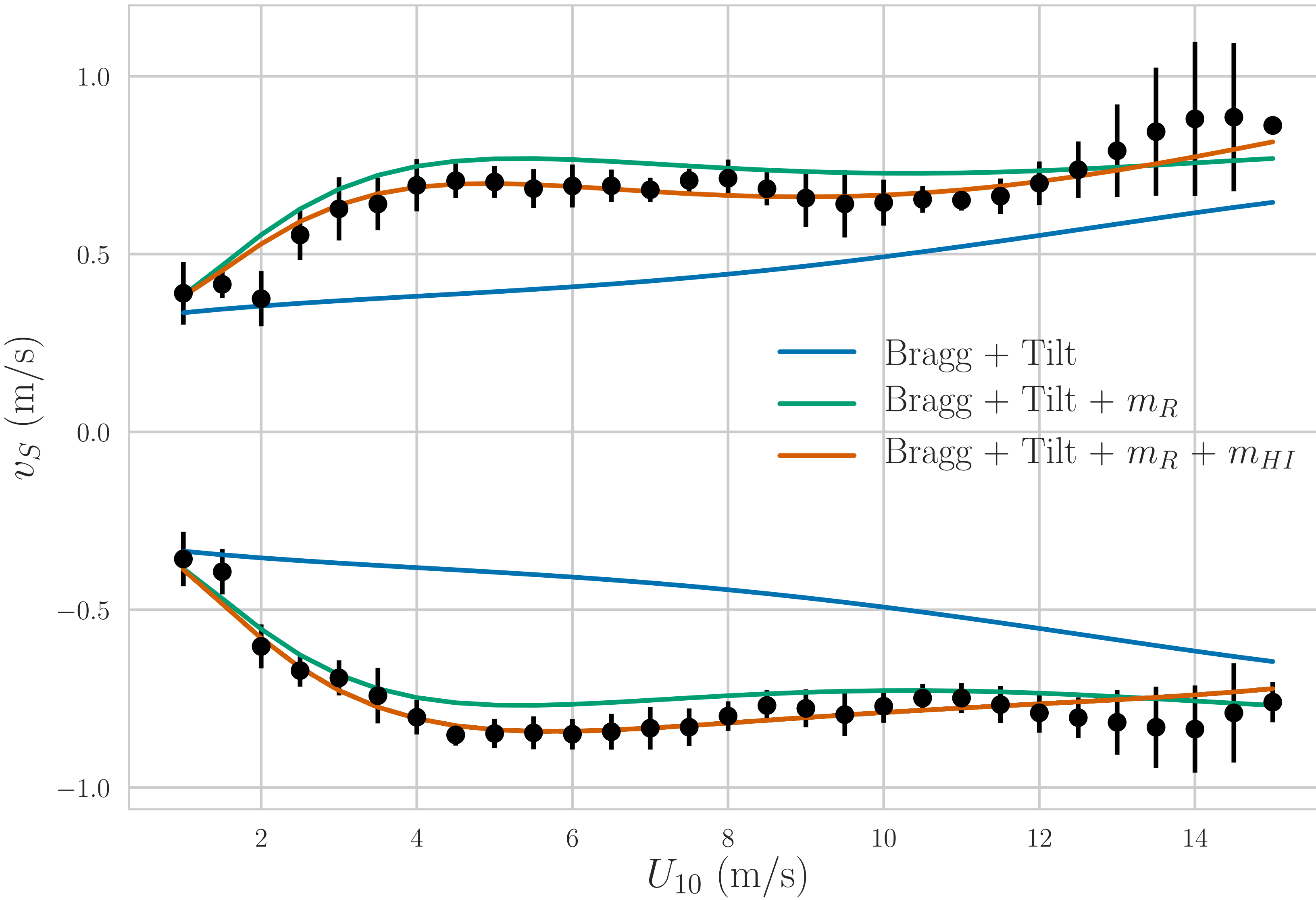
$$\delta v_S = U_S \left[\cos \phi_r m_r + \cot \theta \left(m_i + \cos \phi_r m_T\right)\right]$$

Net gravity wave contribution

$$U_S = \int dk \; k_x \omega F(k_x)$$

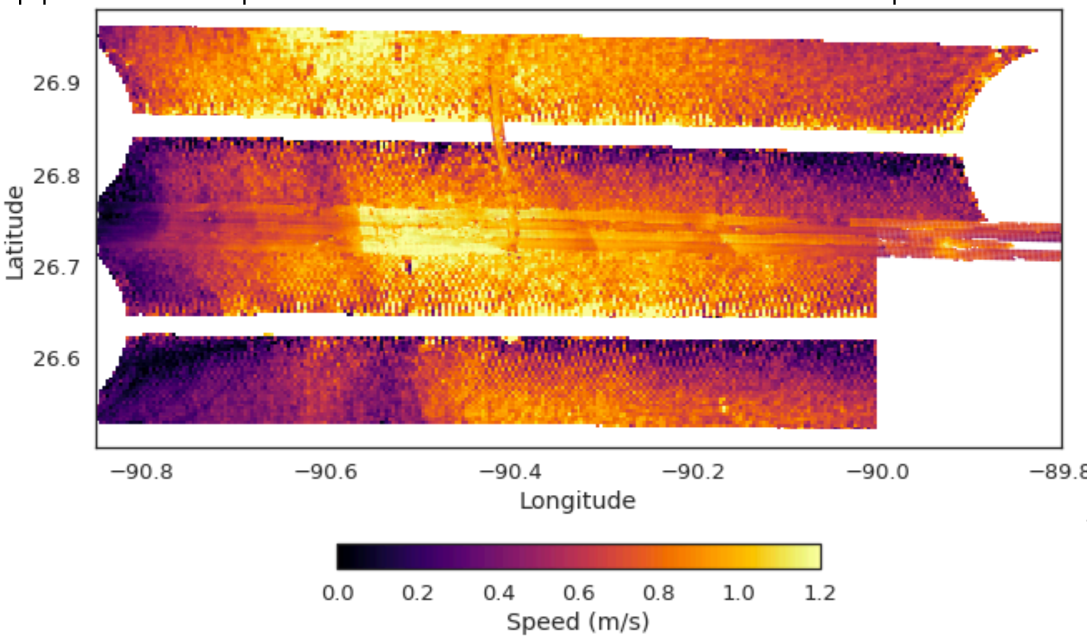
Stokes drift

Upwind/Downwind Velocities vs Theory



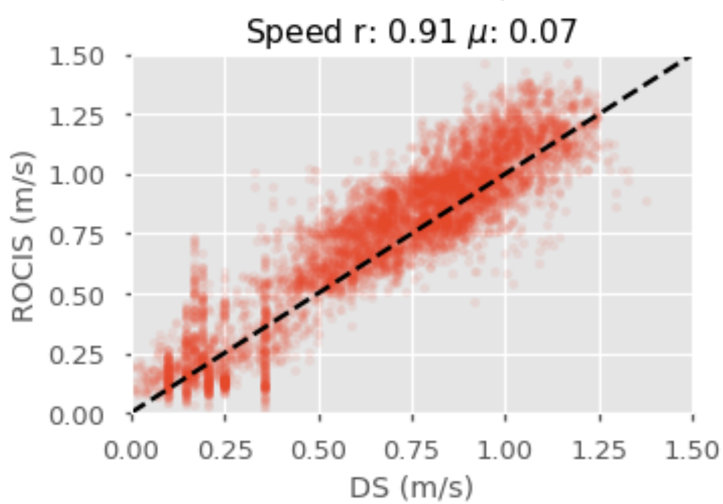
DopplerScatt GoM Eddy Validation

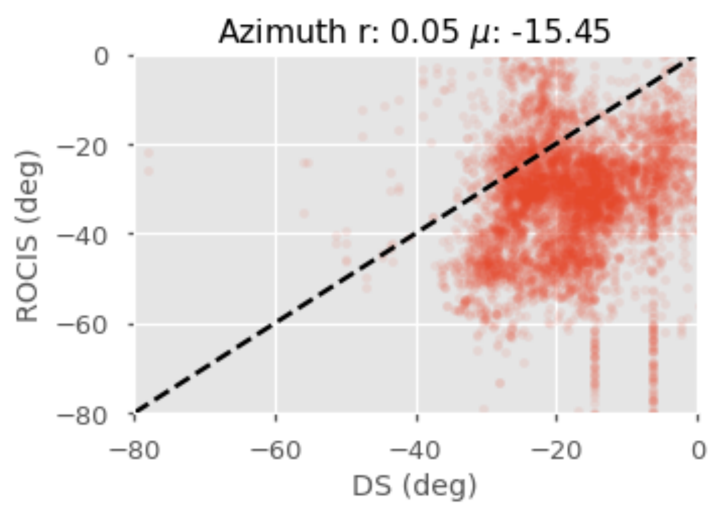
DopplerScatt Speed Data Overlaid with ROCIS Speed Data



In March 2018, DopplerScatt flew over a large Gulf of Mexico Eddy south of New Orleans.

Ocean surface current data were collected at the same time with Fugro's Remote Ocean Current Imaging System (ROCIS) which uses FFT's of space-time ocean wave imagery and the dispersion relation to solve for surface currents.





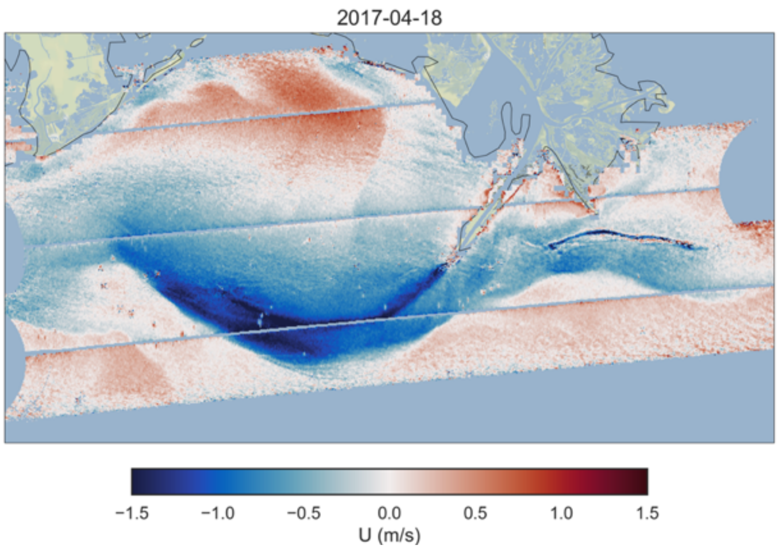
Preliminary results. Analysis on both sides still ongoing.

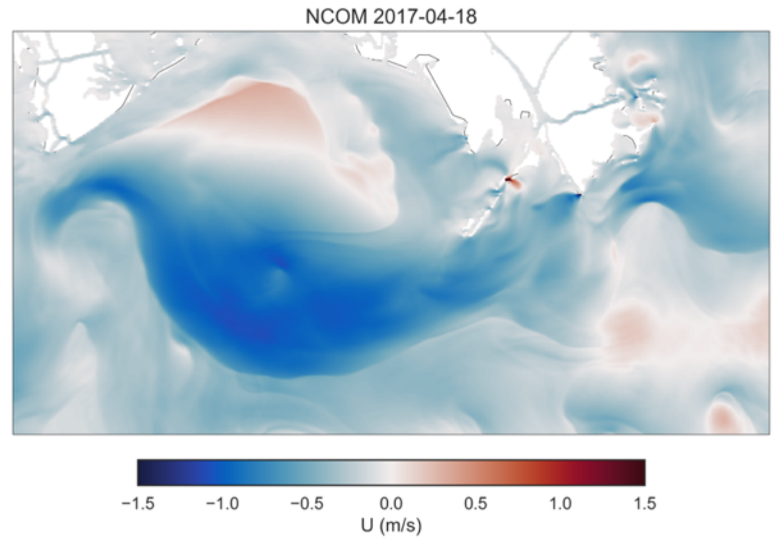
ROCIS data courtesy of Chevron and Fugro.

SPLASH 2017-04-18

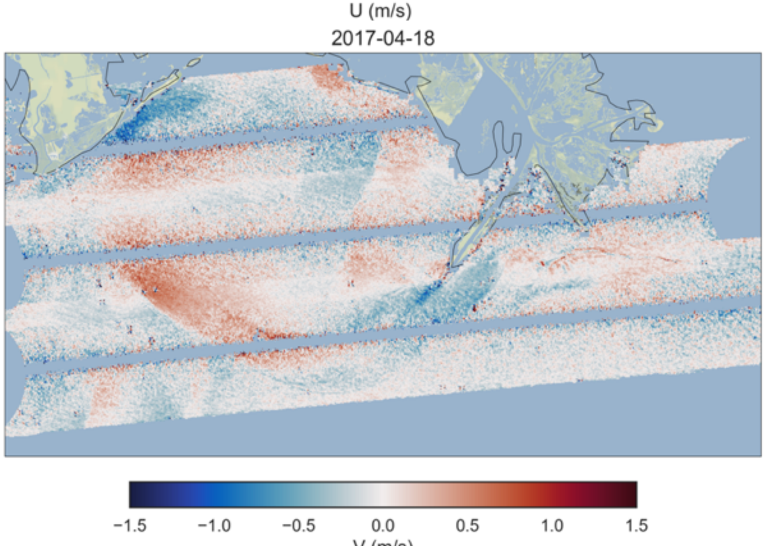
DopplerScatt | NCOM

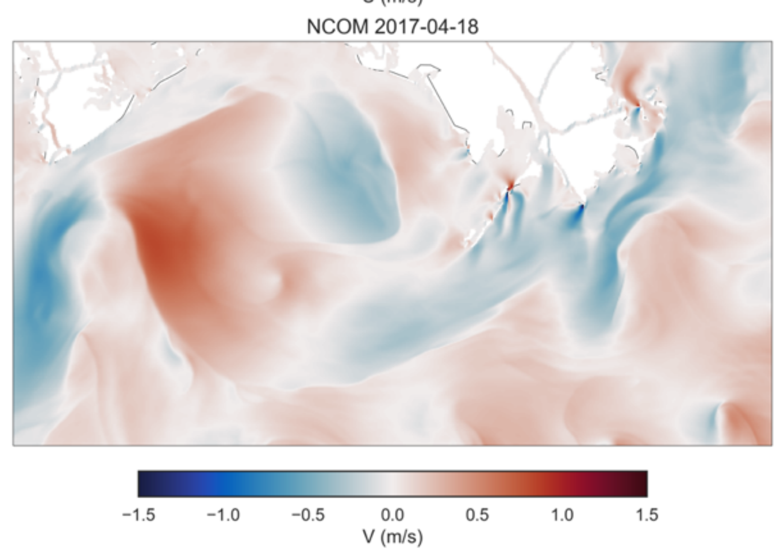
U



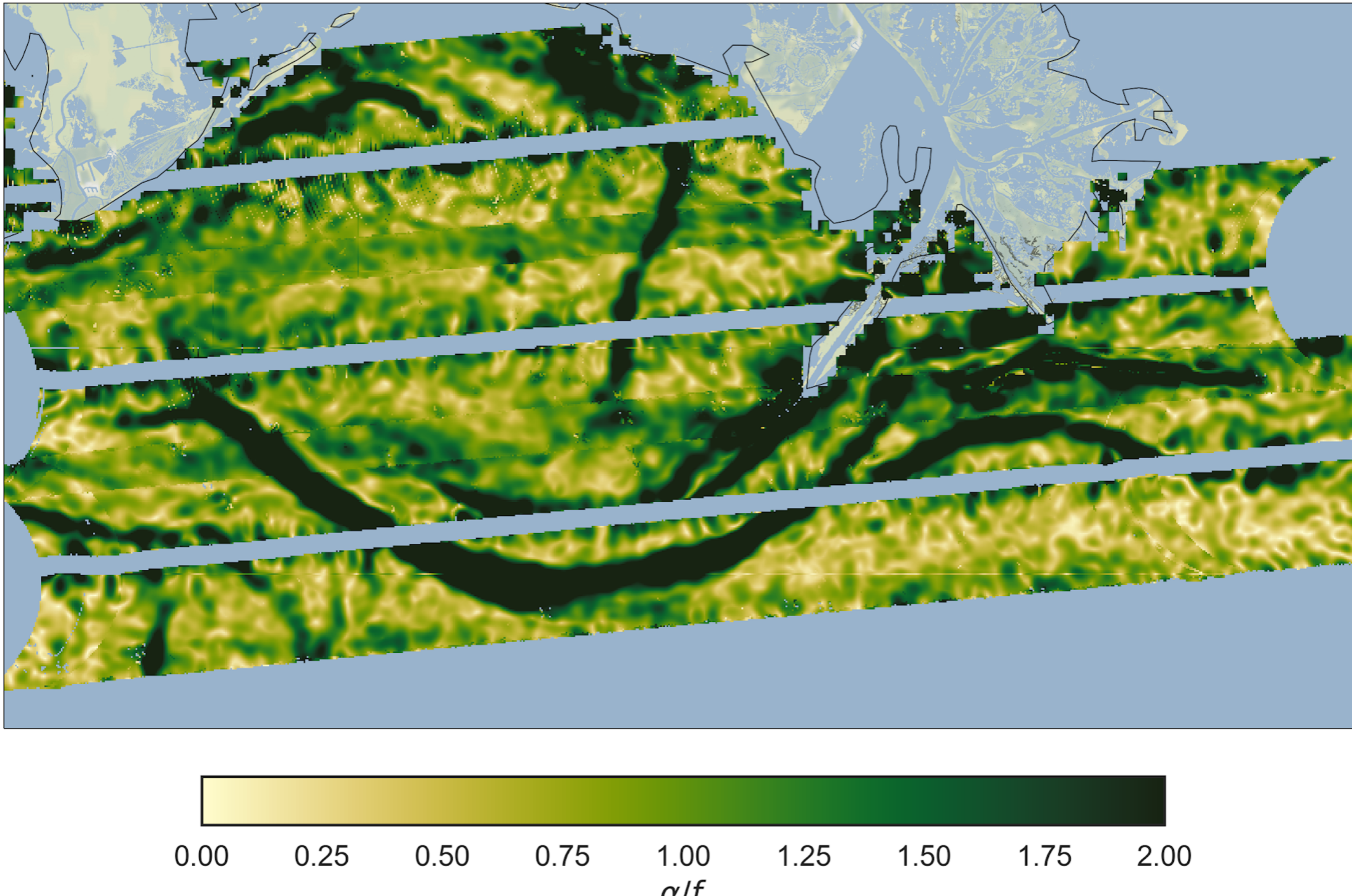


V

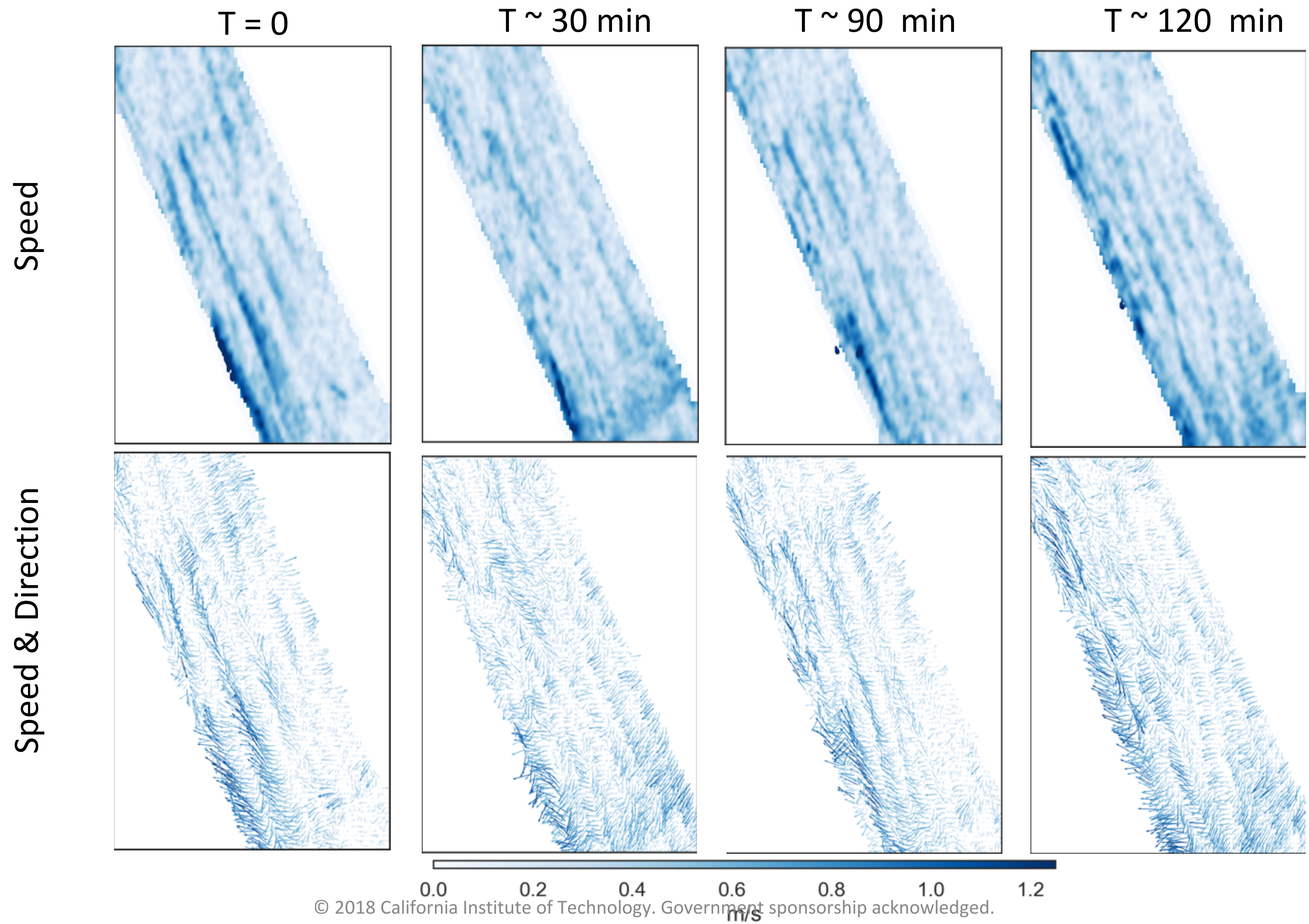




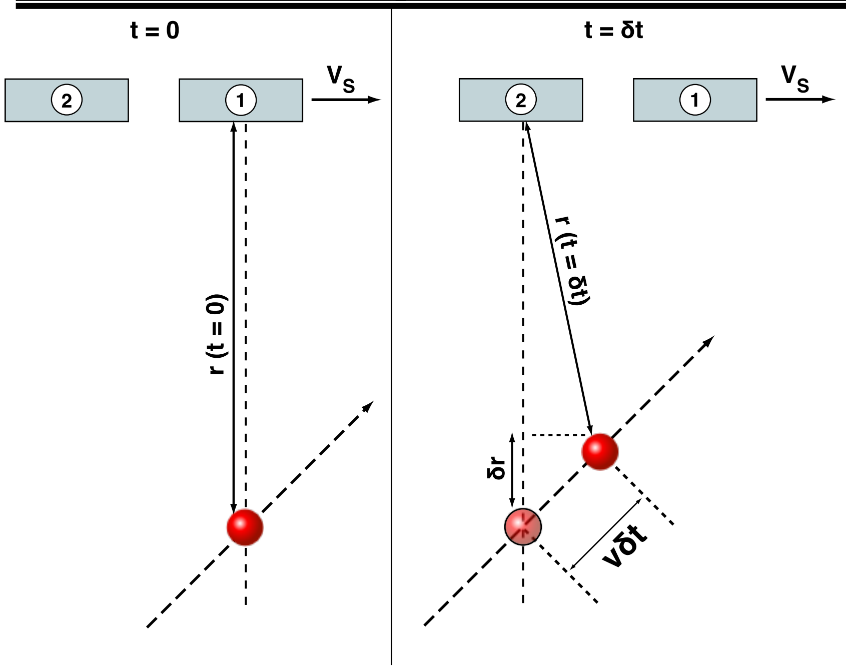
Strain Rate

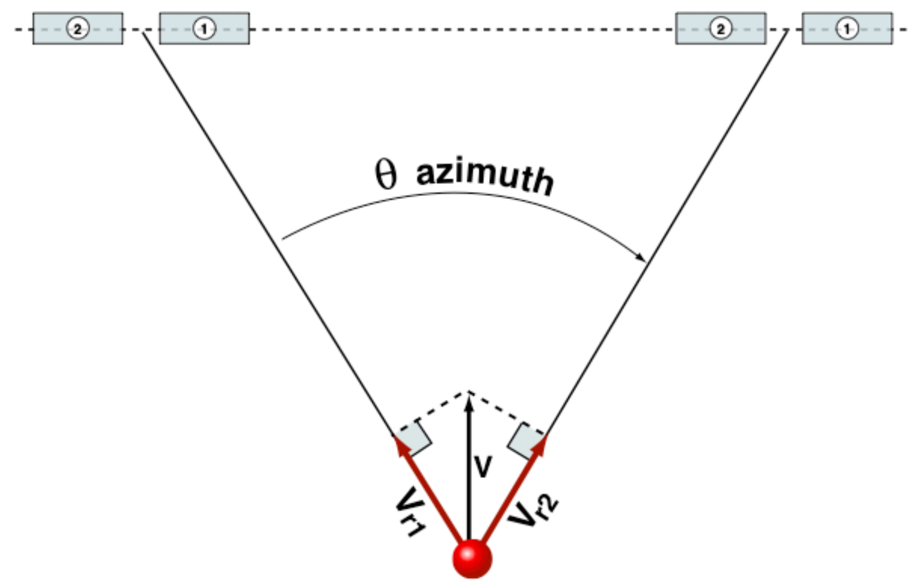


Fast Internal Wave Changes



Doppler Current Measurement Concept





Doppler Phase Difference: $\Delta\Phi = 2k\Delta r = f_D \delta t$

Radial velocity component: $v_r = \Delta r/\delta t = \Delta\Phi/(2k\delta t)$

Vector currents are estimated by combining multiple (≧2) azimuth observations and projecting vector to the ocean surface.

- Radars provide coherent measurements: both the phase and the amplitude of a scattered signal are measured.
- The phase is proportional to the 2-way travel time (or range)
- The amplitude is proportional to the scattering strength of the traget
- Doppler measurements, f_D, are obtained by measuring the phase difference between pulses, $\Delta\Phi$. Noise is reduced by combining multiple pulses.